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JOURNAL OF THE AERONAUTICAL SCIENCES

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The Fundamentals of the Statistical Theory of Turbulence

TH. VON KÁRMÁN, *California Institute of Technology*

Presented at the Fluid Mechanics Session, Fifth Annual Meeting, I. Ae. S. January 27, 1937

Introduction

STATISTICAL theory in general considers mean values of certain quantities. In the case of the turbulent motion one is interested in mean values of velocities and of their derivatives, and in mean values of squares and products of velocities and their derivatives. It was *O. Reynolds* who first expressed the so-called apparent or turbulent stresses by the mean values of the products of the velocity components. The different theories suggested so far have as their common objective the establishment of relations between certain mean values, *e.g.* between the turbulent shear stresses given by the mean products of velocity fluctuations and the derivatives of the mean velocities, *i.e.* the measured mean velocity gradients. In this sort of investigations the conception of the "correlation" is of paramount importance. The late *A. Friedman* tried to introduce the correlations as unknown variables in the hydrodynamic equations; however, he could not carry his investigations to practical results, *i.e.*, to results which can be compared with the experimental evidence. Recently, *G. I. Taylor* had success in his analysis of "isotropic" turbulence by means of correlation calculations, and was able to discuss, theoretically, the problem of the decay of turbulence in a windstream behind a turbulence producing device. His theory raised considerable interest because it is concerned with the important problem of wind-tunnel turbulence and its results could be compared directly with experimental work done by *Dryden* in this country and by *Fage, Townend* and *Simmons* in England.

The present paper is concerned with two fundamental problems: with uniform isotropic turbulence and with the turbulent friction in a parallel stream. First, the general theory of isotropic turbulence is developed.[1] This general theory includes Taylor's consideration as a special case. However, it is shown that Taylor's law of the decay of turbulence is to be considered as a first approximation only. In the second part of the paper, a new theory of turbulent shear motion is developed, which in the opinion of the author, is likely to replace both *Prandtl's* theory of the momentum transfer and *Taylor's* theory of the vorticity transfer. It is hoped that it can be built up with a minimum of additional assumptions to an extensive theory covering the cases of curved and divergent motion, of the motion of a fluid of variable density and of the spread of turbulence.

A. Isotropic Turbulence

Definitions

Consider an indefinitely extended incompressible fluid and assume that one is able to measure the instantaneous values of the velocity components at any arbitrary point P. Denote the velocity components taken in the direction of three orthogonal coordinate axes x_1, x_2, x_3 by u_1, u_2, u_3. It is assumed that the mean values with respect to time of the velocity components are zero, *i.e.* there is no mean motion in the fluid. Furthermore, it is assumed that the turbulence in the fluid is homogeneous and isotropic. This feature is defined mathematically by the assumptions: (a) that the mean values of squares and products of the velocity components and their derivatives are independent of the location of the point observed, and (b) that the same mean values are invariant with respect to rotation and reflection of the coordinate axes.

The mean values considered might be variable with time. However, it will be assumed that the fluctuations are so fast that mean values can be taken over a certain time, during which the variation of the mean values is negligible. The mean values are "slowly variable functions" of the time.

Such conditions exist for instance, in a wind tunnel, and perhaps in some cases in large regions of the atmosphere, especially if one follows certain air masses moving with practically uniform velocity.

[1] The theory presented here was developed by the author in cooperation with L. Howarth. A detailed report containing the exact proofs of the results involved will be published soon, in a joint paper elsewhere.

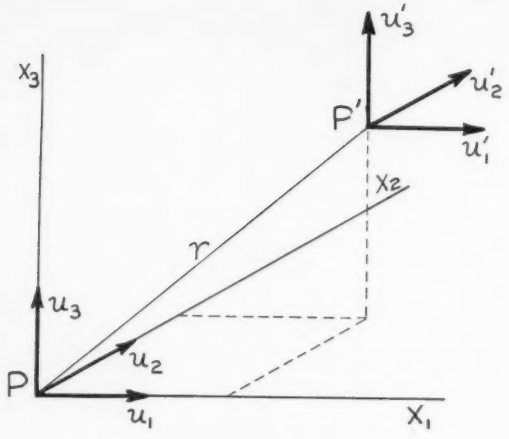

FIG. 1

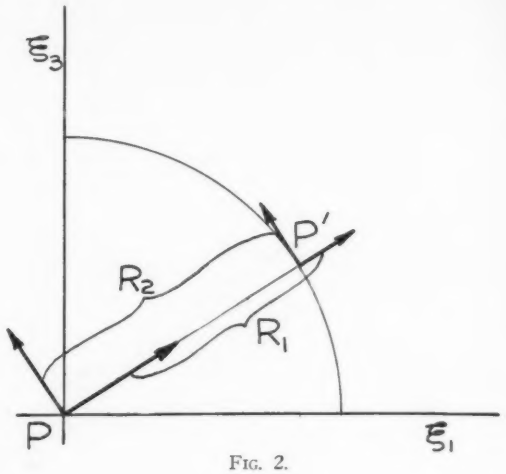

FIG. 2.

THE CORRELATION TENSOR

Consider now the velocity components u_1, u_2, u_3, and u_1', u_2', u_3', measured simultaneously at two arbitrary points P and P' respectively. (See Fig. 1.) The mean values of the squares of all components involved are equal; denote their common value by $\overline{u^2}$. Then define the ratio $R_{ik} = \frac{\overline{u_i u_k'}}{\overline{u^2}}$ as the correlation factor between the component u_i measured at P and the component u_k' measured simultaneously at P'. The quantities u_i and u_k' being components of two vectors, the quantities R_{ik} are components of a "tensor"; call it the "correlation tensor" R. Taking P as a fixed point and varying P', due to the isotropic feature of the turbulence R, considered as a function of the location of P' will be a tensor and spherical symmetry, where the point P is the center of the sphere. Furthermore, $R_{ik}=R_{ki}$ *i.e.* the tensor R is a symmetrical tensor. Such a tensor field can be represented as a stress distribution. For instance, in this case R_{ik} can be considered as the k-component of the stress over a plane normal to the x_i axis. Due to the spherical symmetry the stress components are fully determined by two principal stresses, *i.e.* by the radial stress R_1 and by the transverse stress R_2. (See Fig. 2.) Both are scalar functions of the distance r from the center only, *i.e.* of the distance between the points P and P'. Denoting the projections of r by ξ_1, ξ_2, ξ_3, the tensor R can be written in the following form

$$R = \frac{R_1 - R_2}{r^2} \begin{pmatrix} \xi_1^2 & \xi_1\xi_2 & \xi_1\xi_3 \\ \xi_2\xi_1 & \xi_2^2 & \xi_2\xi_3 \\ \xi_3\xi_1 & \xi_3\xi_2 & \xi_3^2 \end{pmatrix} + R_2 \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \qquad (1)$$

The physical meaning of R_1 and R_2 is evident from the definition of the correlation coefficients R_{ik}: R_1 is the correlation between two velocity components measured in the direction of the connecting line $\overline{PP'}$ and R_2 is the correlation between velocity components taken parallel to each other and normal to $\overline{PP'}$.

THE CONTINUITY EQUATION

The velocity components of an incompressible fluid satisfy the equation of continuity $\Sigma_i \frac{\partial u_i}{\partial x_i} = 0$, where $i = 1, 2, 3$. Hence considering P fixed and P' variable $\Sigma_i \frac{\partial}{\partial \xi_i}(u_k u_i') = 0$ for $k = 1, 2$ or 3. Taking mean values it follows, that $\Sigma_i \frac{\partial R_{ki}}{\partial \xi_i} = 0$. These equations are identical with the conditions that the stresses represented by the components of the tensor R are in equilibrium. In case of spherical symmetry the equilibrium conditions are reduced to one single relation between the radial and transverse principal stresses:

$$r\frac{dR_1}{dr} + 2(R_1 - R_2) = 0 \qquad (2)$$

Using this relation the tensor R is fully determined by one scalar function of r, for instance, by $R_1(r)$.

PRACTICAL USE OF THE CORRELATION TENSOR

In the applications of the correlation calculus it is necessary to find the relations between mean values of the derivatives of the velocity components. *G. I. Taylor* was able to find the relations between the different products of the form $\overline{\frac{\partial u_i}{\partial x_k}\frac{\partial u_j}{\partial x_l}}$; however, he had to carry out quite laborious calculations to this end.

Using the correlation tensor these calculations are largely simplified. It can be shown that

$$\overline{\frac{\partial u_i}{\partial x_k}\frac{\partial u_j}{\partial x_l}} = -\overline{u^2}\left(\frac{\partial^2 R_{ij}}{\partial \xi_k \partial \xi_l}\right)_{\xi_1 = \xi_2 = \xi_3 = 0}$$

Hence, the mean values of the products involved can be found by differentiation of Eq. (1). It is easy to see that due to Eqs. (1) and (2) all mean products of the form considered reduce to the form

$$\text{numerical constant} \times \overline{u^2} \times \left(\frac{d^2 R_1}{dr^2}\right)_{r=0}$$

The last factor is the reciprocal of the square of a length. Due to *Eq.* (2) $\left(\frac{d^2R_1}{dr^2}\right)_{r=0} = \frac{1}{2}\left(\frac{d^2R_2}{dr^2}\right)_{r=0}$; on the other hand $\frac{1}{2}\left(\frac{d^2R_2}{dr^2}\right)_{r=0} = -\frac{1}{\lambda^2}$, where λ is the length introduced as the "dimension of the smallest eddies" by Taylor. The exact definition of λ is given by the r coordinate of the intersection of the parabola, which approximates the correlation function $R_2(r)$ at the origin, with the r—axis. (See Fig. 3.)

Hence, it is found that all squares and products of the derivatives of the velocities can be expressed in the form

$$\text{numerical constant} \times \frac{\overline{u^2}}{\lambda^2}$$

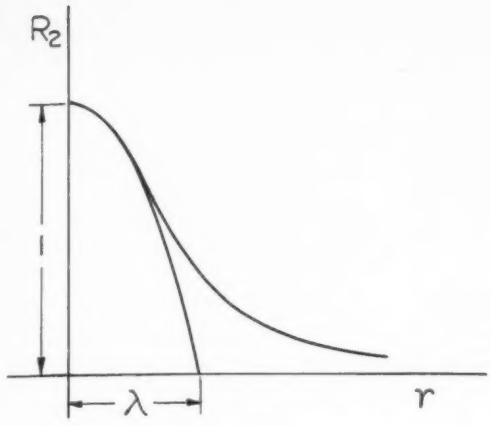

FIG. 3.

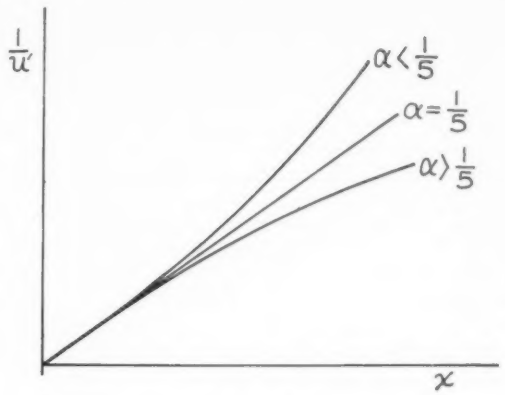

FIG. 4.

THE PROPAGATION OF THE CORRELATION WITH TIME

Assume now, that the quantities R_{ik} are slowly variable functions of the time and investigate the change of the correlation factors when the fluid is not influenced by external forces.

The differential equations of the motion are

$$\frac{\partial u_i}{\partial t} + \Sigma_j u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \nu \Delta u_i \tag{3}$$

(ν = kinematic viscosity, p = pressure). Multiplying Eqs. (3) by u'_k equations for the products $u_i u'_k$ and, taking mean values over time and space, differential equations for the correlation factor R_{ik} are obtained. The result is

$$\frac{\partial}{\partial t}(R_{ik}\,\overline{u^2}) = 2\nu\overline{u^2}\Delta R_{ik} \tag{4}$$

where $\Delta = \frac{\partial^2}{\partial \xi_1^2} + \frac{\partial^2}{\partial \xi_2^2} + \frac{\partial^2}{\partial \xi_3^2}$. Because of Eqs. (1) and (2), Eqs. (4) can be replaced by one single equation for the scalar correlation function R_1:

$$\frac{\partial}{\partial t}(R_1\,\overline{u^2}) = 2\nu\overline{u^2}\left(\frac{\partial^2 R_1}{\partial r^2} + \frac{4}{r}\frac{\partial R_1}{\partial r}\right) \tag{5}$$

Now applying this equation when $r = 0$ and taking into account, that $R_1(0) = 1$ for all time and $\left(\frac{dR_1}{dr}\right)_{r=0} = 0$, one obtains

$$\frac{d\overline{u^2}}{dt} = 10\,\nu\,\overline{u^2}\left(\frac{d^2R_1}{dr^2}\right)_{r=0} \tag{6}$$

or

$$\frac{d\overline{u^2}}{dt} = -10\,\nu\frac{u^2}{\lambda^2} \tag{7}$$

(Because $\overline{u^2}$ is a function of t only, d/dt is substituted for $\partial/\partial t$) Eliminating $\overline{u^2}$ from Eqs. (5) and (7) the fundamental partial equation for the propagation of the correlation

$$\frac{\partial R_1}{\partial t} = 2\nu\left[\frac{\partial^2 R_1}{\partial r^2} + \frac{4}{r}\frac{\partial R_1}{\partial r} + \frac{5}{\lambda^2}R_1\right] \tag{8}$$

is obtained. This equation determines R_1 (r, t) for all subsequent times, if *e.g.*, R_1 for $t=0$ is given.

If the initial shape of the correlation function R_1 (r, o) is arbitrary its shape will in general change with time. However, there are particular cases in which the shape of the correlation function remains similar. This will occur if R_1 (r, t) is a function of the dimensionless variable $X = \frac{r}{\sqrt{\nu t}}$ only. Then Eq. (8) is reduced to $\frac{d^2R_1}{dX^2} + \left(\frac{4}{X} + \frac{X}{4}\right)\frac{dR_1}{dX} + 5\alpha R_1 = 0$ (9)

where α is a numerical factor, equal to $-\left(\frac{d^2R_1}{dX^2}\right)_{X=0}$. In this case obviously $\left(\frac{\partial^2 R_1}{\partial r^2}\right)_{r=0} = \frac{1}{\nu t}\left(\frac{d^2R_1}{dX}\right)_{X=0}$ and taking into account that $\frac{1}{\lambda^2} = -\left(\frac{d^2R_1}{dr^2}\right)_{r=0}$

$$\lambda^2 = \frac{1}{\alpha}\,\nu t \tag{10}$$

Hence, if the shape of the correlation function remains similar, λ^2 increases linearly with time and the numerical factor α determines the rate of increase; α itself is given by the initial shape of R_1.

THE DECAY OF TURBULENCE

Eq. (10) gives the rate of increase of the eddy-dimension λ. Substituting Eq. (10) in Eq. (7) one obtains

$$\frac{d\overline{u^2}}{dt} = -10\,\alpha\frac{\overline{u^2}}{t} \tag{11}$$

i.e

$$\overline{u^2} = \text{const}/t^{10\alpha} \tag{12}$$

Apply this result to the problem of the decay of turbulence in a uniform windstream downstream from a grid or mesh. This problem was treated by *G. I. Taylor*. In this case, the fluid is supposed to move with a uniform velocity U in the direction of the x axis. Hence, considering the fluid element which at the instant $t=t_0$ is located at $x=0$, $t=t_0 + x/U$. Assuming that at $t = t_0$, $u^2 = u_0^2$; from Eq. (12) it follows that

$$\overline{u^2} = \overline{u_0^2}/\left(1 + \frac{x}{Ut_0}\right)^{10\alpha} \tag{13}$$

The length λ is given by Eq. (10) and can be written (with $\lambda = \lambda_0$ when $x=0$)

$$\lambda^2 = \alpha\,\nu\left(t_0 + \frac{x}{U}\right) = \lambda_0^2 + \alpha\,\nu\frac{x}{U} \tag{14}$$

G. I. Taylor's result is

$$\frac{1}{\sqrt{\overline{u^2}}} = \frac{1}{\sqrt{\overline{u_0^2}}} + \text{const.}\frac{x}{U} \tag{15}$$

Obviously Eq. (13) yields this equation as first approximation if the denominator is developed in a series of powers of x; or as an exact result if $\alpha=1/5$.

Fig. 4 shows $\frac{1}{u'}=\sqrt{\frac{1}{u^2}}$ as function of x for $\alpha<\frac{1}{5}$, $\alpha=\frac{1}{5}$ and $\alpha>\frac{1}{5}$

Taylor obtained Eq. (15) by assuming rather arbitrarily a relation between the length λ defined above and the linear dimension, *e.g.* the spacing M at the grid or mesh. He assumes that for meshes with similar geometrical arrangement, *e.g.* for all square meshes, the quantity $\lambda^2\sqrt{\overline{u^2}}/\nu$ is proportional to M, independently of the shape and dimensions of the cross section of the bars which form the mesh and produce the turbulence. Such a relation might be admitted for a particular location, *e.g.* the section in which the individual windshadows of the bars disappear. Such a section can be considered as the initial section $x=0$ and the values t_0, $\overline{u^2_0}$, λ_0 can be associated with this section. Then this analysis shows, that in general $\lambda^2\sqrt{\overline{u^2}}$ will be variable with x because from Eqs. (13) and (14) it follows that

$$\frac{\sqrt{\overline{u^2}}\,\lambda^2}{\sqrt{\overline{u_0^2}}\,\lambda_0^2}=\left(1+\frac{x}{Ut_0}\right)^{1-5\alpha} \tag{16}$$

According to Taylor's assumption $\sqrt{\overline{u^2}}\,\lambda^2/\nu$ should be constant downstream from the initial section. It is seen that this result is only correct if again $\alpha=1/5$.

Energy and Vorticity Dissipation

Eq. (7) will be called the equation of energy dissipation. It connects the differential quotient of the square of velocity with respect to time with the length λ. A similar equation can be established for the dissipation of the mean square of the absolute magnitude of the vorticity vector or for the sum of the mean squares of the three vorticity components. This equation can be deduced from the partial differential Eq. (8); however, it is preferable to give a direct deduction having regard to further applications in part B.

Denote the three components of the vorticity by ω_1 ω_2 ω_3 where for instance $\omega_1=\frac{\partial u_3}{\partial x_2}-\frac{\partial u_2}{\partial x_3}$, and ω_2, ω_3 are obtained by cyclic permutation of the subscripts. Then the hydrodynamic Eqs. (4) lead by elimination of the pressure to the following relations ($i=1, 2, 3$)

$$\frac{\partial\omega_i}{\partial t}+\Sigma_k u_k\frac{\partial\omega_i}{\partial x_k}-\Sigma_k\omega_k\frac{\partial u_i}{\partial x_k}=\nu\,\Delta\,\omega_i \tag{17}$$

Multiplying by ω_i and adding the three equations ($i=1, 2, 3$) furthermore writing ω^2 for $\Sigma_i\,\omega_i^2$ one obtains

$$\frac{1}{2}\frac{\partial\omega^2}{\partial t}+\frac{1}{2}\Sigma_k u_k\frac{\partial\omega^2}{\partial x_k}-\Sigma_i\Sigma_k\,\omega_i\,\omega_k\frac{\partial u_i}{\partial x_k}=\nu\Sigma\,\omega_i\,\Delta\omega_i \tag{18}$$

Taking mean values, it is found that

(a) In the case of homogeneous isotropic turbulence at the left side of Eq. (18) only the first term remains, because mean values of triple products vanish. Instead of the sign for partial differentiation, write d/dt.

(b) The expression multiplied by ν at the right side can be transformed by partial integration to $\frac{1}{2}\Delta\,\omega^2-\Sigma_i\Sigma_k\overline{\left(\frac{\partial\omega_i}{\partial x_k}\right)^2}$. The mean value of the first term of this expression vanishes for isotropic homogeneous turbulence. The second term can be expressed by derivatives of the correlation function R_1 because ω_i is a combination of derivatives of the velocity components u_i. The calculation carried out along the lines indicated in the section, on "Practical Use of the Correlation Tensor", results in the relation

$$\Sigma_i\Sigma_k\overline{\left(\frac{d\omega_i}{dx_k}\right)^2}=-\frac{7}{3}\overline{\omega^2}\frac{\left(\frac{d^4R_1}{dr^4}\right)_{r=0}}{\left(\frac{d^2R_1}{dr^2}\right)_{r=0}}=\frac{7}{3}\overline{\omega_2}\,\lambda^2\,\overline{\left(\frac{d^4R_1}{dr^4}\right)}_{r=0} \tag{19}$$

The quantity $\lambda^2\left(\frac{d^4R_1}{dr^4}\right)_{r=0}$ is the reciprocal of the square of a length. Hence $\Sigma\Sigma\overline{\left(\frac{\partial\omega_i}{\partial x_k}\right)^2}$ has the form const. $\times\frac{\overline{\omega^2}}{\lambda^2}$ and we define in particular—in order to obtain analogy with the energy equation—λ_ω by $\lambda_\omega^2=\frac{15}{7\,\lambda^2\left(\frac{d^4R}{dy^4}\right)_{r=0}}$

Then from equation (18) follows

$$\frac{d\overline{\omega^2}}{dt}=-2\,\nu\,\Sigma_i\Sigma_k\overline{\left(\frac{\partial\omega_i}{\delta x_k}\right)^2}=-10\,\nu\,\frac{\overline{\omega^2}}{\lambda_\omega^2} \tag{20}$$

If the correlation is such, that its shape is unaltered and its scale changes only $\lambda^2/\lambda^2_\omega$=const.; if, especially, Taylor's linear law for the reciprocal of $\sqrt{\overline{u^2}}$ is correct $\lambda^2/\lambda_\omega^2=3/2$. The factor α of the general theory is equal to $2/5(\lambda^2/\lambda_\omega^2-1)$.

The conception of the dissipation of energy and vorticity is the starting point to the theory of shear motion presented in part B of this paper.

B. Parallel Shear Motion

Momentum and Vorticity Transfer

The mechanism of turbulent friction in the case of a stationary parallel mean flow is the second fundamental problem in the statistical theory of turbulence. *L. Prandtl* and *G. I. Taylor* suggested different methods for the calculation of the velocity distribution in such a motion. Prandtl's theory is based on the conception of momentum transfer. He assumes that fluid particles carry their momentum unaltered over a certain length. *G. I. Taylor* objected to the idea of momentum transfer and substituted for it the conception of vorticity transfer. The author believes that neither of these suggestions can lead to a real understanding of the mechanism of turbulent motion for the following reason.

Consider for the sake of simplicity two dimensional mean flow in the direction of the x_1 axis and assume that the mean velocity is a function of the x_2 coordinate only. Then Prandtl's theory of momentum transfer starts from *O. Reynolds* expression for the total shearing stress (including laminar and turbulent friction)

$$\tau=-\rho\,\overline{u_1u_2}+\mu\frac{dU}{dx_2} \tag{1}$$

where U is the mean value of u_1.

On the other hand the conception of the vorticity transfer is based on the equation for the mean pressure gradient existing in the direction of the x_1-axis

$$\frac{d\bar{p}}{dx_1}=-\rho\frac{\partial}{\partial x_2}(\overline{u_1u_2})+\mu\frac{d^2U}{dx_2^2}=\rho(\overline{u_2\omega_3}-\overline{u_3\omega_2})+\mu\frac{d^2U}{dx_2^2} \tag{2}$$

Now the experimental evidence shows that for large Reynolds numbers the terms containing μ are extremely small in comparison with the terms containing the density and the mean

products of velocity components or velocity components and their derivatives. However, from the classical investigations of *O. Reynolds* and *H. A. Lorentz* it is known that the development of turbulence depends on the balance between the transfer of energy from the mean motion into the fluctuations and the dissipation due to the fluctuations. Hence, it is extremely unlikely that the mechanism of the turbulence should be determined by equations, in which the influence of the viscosity terms vanishes with increasing Reynolds number. It seems to the author that this would be only possible if, practically, dissipation would take place only in the laminar sublayer which exists in immediate neighborhood of walls. However, this is apparently not the case.

The main objective of this paper is to show that the conception of dissipation of energy and that of dissipation of vorticity furnish two equations in which the inertia and viscosity terms balance each other at arbitrarily large Reynolds numbers. Hence, it is the belief of the author that these equations are the fundamental equations of a satisfactory theory of turbulence.

Energy Transport and Energy Dissipation

First, investigate the equation for the dissipation of energy from this standpoint. From Eqs. (3) of part A it follows, by multiplication by u_i and addition of the three equations, that

$$\frac{1}{2}\frac{\partial u^2}{\partial t}+\frac{1}{2}\Sigma_i u_i\frac{\partial u^2}{\partial x_i}=-\Sigma_i\frac{u_i}{\rho}\frac{\partial p}{\partial x_i}+\nu\Sigma_i u_i\,\Delta u_i \qquad (3)$$

By partial integration the last term at the right side can be transformed into

$$\nu\Sigma_i\frac{\partial^2}{\partial x_i^2}\frac{u^2}{2}-\nu\Sigma_i\Sigma_k\left(\frac{\partial u_i}{\partial x_k}\right)^2$$

Denote the mean value of u_1 by U and assume that the mean values of u_2 and u_3 are zero. Hence, write $u_1=U+u'_1$, $u_2=u'_2$ $u_3=u_3'$, where u_1', u'_2, u_3' are the components of the velocity fluctuation. Furthermore, write $u'^2_1+u'^2_2+u'^2_3=q^2$. Taking mean values over time and over the coordinates x_1 and x_3, one obtains from Eq. (3)

$$\frac{d}{dx_2}\left[\overline{u_2'\left(\frac{q^2}{2}+\frac{p}{\rho}\right)}\right]+U\left[\frac{1}{\rho}\frac{d\bar{p}}{dx_1}+\frac{d}{dx_2}\overline{(u_1'u_2')}-\nu\frac{d^2U}{dx_2^2}\right]$$
$$+\overline{u_1'u_2'}\frac{dU}{dx_2}=\nu\frac{d^2}{dx_2^2}\frac{\bar{q}^2}{2}-\nu\Sigma_i\Sigma_k\overline{\left(\frac{\partial u_i'}{\partial x_k}\right)^2} \qquad (4)$$

The factor of U (in the bracket) vanishes because of Eq. (2). Furthermore from Eq. (1) $\overline{u_1u_2}=-\frac{\tau}{\rho}+\nu\frac{dU}{dx_2}$. Hence, Eq. (4) reduces to

$$-\frac{d}{dx_2}\left[\overline{u_2'\left(\frac{q^2}{2}+\frac{p}{\rho}\right)}\right]+\frac{\tau}{\rho}\frac{dU}{dx_2}=-\nu\frac{d^2}{dx_2^2}\frac{\bar{q}^2}{2}+\nu\left(\frac{dU}{dx_2}\right)^2$$
$$+\nu\Sigma_i\Sigma_k\overline{\left(\frac{\partial u_i'}{\partial x_k}\right)^2} \qquad (5)$$

Now compare the order of magnitude of the particular terms in Eq. (5) in the case of large Reynolds numbers. First, notice that the total differential quotients represent derivatives of mean values with respect to the coordinate x_2, *i. e.* normal to the direction of the mean motion; the partial differential quotients are derivatives of the fluctuations. It is known that if the Reynolds number increases, the subdivision of the turbulent velocity field—the structure of the microturbulence, using Taylor's expression—becomes finer and finer. The length λ introduced in part A can be considered as a measure of the subdivision of the velocity field. Hence, it can be said that the mean values of the form $\overline{\left(\frac{\partial u_i'}{\partial x_k}\right)^2}$ are of the order $\frac{q^2}{\lambda^2}$.

To express the order of magnitude of the derivatives of the mean values with respect to x_2, the length L is introduced, representing a characteristic linear dimension of the mean flow (for instance, the distance between the walls, which enclose the fluid). Then the differential operator d/dx_2 is equivalent to a factor $1/L$ as far as order of magnitude is concerned.

The order of magnitude of the five terms in Eq. (5) are shown in the following line

$$\underbrace{-\frac{d}{dx_2}\left[\overline{u_2'\left(\frac{q^2}{2}+\frac{p}{\rho}\right)}\right]}_{\frac{q^3}{L}}+\underbrace{\frac{\tau}{\rho}\frac{dU}{dx_2}}_{\frac{q^3}{L}}=\underbrace{-\nu\frac{d^2}{dx_2^2}\frac{\bar{q}^2}{2}}_{\frac{\nu q^2}{L^2}}+\underbrace{\nu\left(\frac{dU}{dx_2}\right)^2}_{\frac{\nu q^2}{L^2}}$$
$$\underbrace{\mp\nu\Sigma_i\Sigma_k\overline{\left(\frac{\partial u_i'}{\partial x_k}\right)^2}}_{\frac{\nu q^2}{\lambda^2}} \qquad (6)$$

The order of magnitude of τ/ρ follows from Eq. (1): $\frac{\tau}{\rho}\sim q^2$. Furthermore, it is known by experimental evidence that

$$\frac{dU}{dx_2}\sim\frac{\sqrt{\frac{\tau}{\rho}}}{L}\sim\frac{q}{L}.$$

The absolute value of U does not enter into the equations.

Now for large Reynold's numbers $\frac{qL}{\nu}>>1$, and therefore $\frac{q^3}{L}>>\frac{\nu q^2}{L^2}$. On the other hand it will be seen that the remaining terms on the left and right sides of the equation are of the same order of magnitude if $\frac{q\lambda^2}{\nu L}\sim 1$. This result is of fundamental importance for an adequate theory of turbulence. In the belief of the author it opens the way to the correct understanding of the mechanism of the turbulent exchange in the same way that *Prandtl's* analysis of the order of magnitude of the terms in the boundary layer equation gave the clue to the understanding of the phenomena of laminar skin friction.

Neglecting the terms of the order $\frac{\nu q^2}{L^2}$ Eq. (5) (or (6)) reads

$$-\frac{d}{dx_2}\left[\overline{u_2'\left(\frac{q^2}{2}+\frac{p}{\rho}\right)}\right]+\frac{\tau}{\rho}\frac{dU}{dx_2}=\nu\Sigma_i\overline{\left(\frac{\partial u_i'}{\partial x_k}\right)^2} \qquad (7)$$

or

$$-\frac{d}{dx_2}\left[\overline{\rho u_2'\left(\frac{q^2}{2}+\frac{p}{\rho}\right)}\right]+\tau\frac{dU}{dx_2}=\mu\Sigma_i\Sigma_k\overline{\left(\frac{\partial u_i}{\partial x_k}\right)^2} \qquad (7a)$$

This equation can be interpreted from a physical standpoint as follows: $\rho\left(\frac{q^2}{2}+\frac{p}{\rho}\right)$ is defined as the energy of the velocity fluctuations per unit volume; then $\rho u_2'\left(\frac{q^2}{2}+\frac{p}{\rho}\right)$ is the energy flux carried by convection through unit surface of the x_1 x_3 plane. Hence, the first term at the left side is the energy entering by convection into a unit volume element minus the energy carried out by convection. The second term represents the work done by the stress τ. The right side represents the energy dissipation by viscosity.

The Equation for Vorticity Dissipation

The equation for the dissipation of vorticity can be deduced in an analogous manner. From equations (17) part *A*, it follows by multiplication by ω_i and addition that

$$\frac{1}{2}\frac{\partial \omega^2}{\partial t} + \frac{1}{2}\Sigma_i u_i \frac{\partial \omega^2}{\partial x_i} + \Sigma_i \Sigma_k \omega_i \omega_k \frac{\partial u_i}{\partial x_k} = \Sigma \nu \omega_i \Delta \omega_i \qquad (8)$$

The second term at the left can be transformed by partial integration into $\Sigma \frac{\partial}{\partial x_i}\left(u_i \frac{\omega^2}{2}\right)$. The third term requires special consideration. It was mentioned in part *A* that it vanishes in the case of isotropic turbulence; also, it can be easily seen that it is identically zero for pure two dimensional motion. In that case only one component is different from zero, *e.g.* ω_3 if the motion takes place in the $x_1 x_2$ plane; hence the whole expression is reduced to $\omega_3^2 \frac{\partial u_3}{\partial x_3}$, and because $u_3 = 0$, this only remaining term also vanishes. It will be assumed in this paper that the expression $\Sigma_i \Sigma_k \omega_i \omega_k \frac{\partial u_i}{\partial x_k}$ is zero also in the three dimensional case. It is the scalar product of two tensors; one tensor consists of the dyadic product $\omega_i \omega_k$ of the vorticity components. The other tensor is the so-called deformation tensor. If an arbitrary point of the fluid is considered at an arbitrary instant and the coordinate axes chosen such that the x_3 axis coincides with the direction of the vorticity vector, the total expression is reduced again to $\omega_3^2 \frac{\partial u_3}{\partial x_3}$. If the mean value of this expression were different from zero this would mean a certain permanent tendency for stretching or shortening of the fluid elements in the direction of the vorticity vector. The author cannot see any physical reason for such a correlation; however, it is readily admitted that the vanishing of this term is a rather arbitrary assumption of the new theory.

Neglecting the term in question and taking mean values. Eq. (8) reduces to

$$\frac{d}{dx_2}\left(\overline{u_2 \frac{\omega^2}{2}}\right) = \nu \Sigma_i \overline{\omega_i \Delta \omega_i} \qquad (9)$$

Now separate the mean values of the quantities ω_i and the fluctuations ω_i'. For the case of two dimensional parallel mean flow, which is being considered, only the mean value of ω_3 is different from zero. Write $\overline{\omega_3} = \Omega = -\frac{dU}{dx_2}$. Then the left of Eq. (9) is equal to $\Omega \frac{d}{dx_2}\left(\overline{u_2' \omega_3'}\right) + \overline{u_2' \omega_3'} \frac{d\Omega}{dx_2} + \frac{d}{dx_2}\left(\overline{u_2' \frac{\omega_3'^2}{2}}\right)$, where ω'^2 is written for $\omega_1'^2 + \omega_2'^2 + \omega_3'^2$. Now Ω is of the order of $\frac{q}{L}$ and ω' is of the order of q/λ. Consequently, the first two terms containing Ω and $\frac{d\Omega}{dx_2}$ are small in comparison with the last term, which is merely a combination of the velocity fluctuations and their derivatives. The right side of Eq. (9) can be first transformed into $\frac{d}{dx_2}\frac{\overline{\omega^2}}{2} - \nu \Sigma_i \Sigma_k \overline{\left(\frac{\partial \omega_i}{\partial x_k}\right)^2}$ by partial integration. Then introducing $\omega_3 = \Omega + \omega_3'$ and discussing the order of magnitude of the particular terms, it is found that the largest term is

$-\nu \Sigma_i \Sigma_k \overline{\left(\frac{\partial \omega_i'}{\partial x_k}\right)^2}$. Hence, the equation (9) is reduced to

$$-\frac{d}{dx_2}\left(\overline{u_2' \frac{\omega'^2}{2}}\right) = \nu \Sigma_i \Sigma_k \overline{\left(\frac{\partial \omega_i'}{\partial x_k}\right)^2} \qquad (10)$$

It is remarkable that in this equation the mean value of the vorticity vector does not appear at all. Hence, the physical character of the equation is quite different from the equation suggested by *Taylor* in his vorticity transfer theory. It is seen that the term at the left side of the equation is of the order $\frac{q^3}{L\lambda^2}$, the term at the right side of the equation is of the order $\frac{\nu q^2}{\lambda^4}$. They are of the same order of magnitude if $\frac{q\lambda^2}{\nu L} \sim 1$. The same fundamental relation between the quantities involved in the mechanism of the turbulence is found again.

The physical interpretation of Eq. (10) is the following: the half sum of the mean squares of the components of the vorticity fluctuation will be defined as the "mean eddy vorticity." Then the left side of Eq. (10) gives the excess of mean eddy vorticity entering into the volume element over the amount which is carried out of the same element. The expression on the right side represents the dissipation of the mean eddy vorticity.

Turbulent Diffusion

The next objective is the discussion of the terms which represent the transport of mean energy and mean eddy vorticity from layer to layer. The average value of $\rho u_2' \left(\frac{q^2}{2} + \frac{p}{\rho}\right)$ is interpreted as energy flux and the average value of $u_2' \frac{\omega'^2}{2}$ as vorticity flux. It is known that both expressions vanish for homogeneous isotropic turbulence. Hence, it is assumed that there is correlation between the velocity u'_2 and $\left(\frac{q^2}{2} + \frac{p}{\rho}\right)$ or $\frac{\omega'^2}{2}$ respectively if the mean values $\frac{\overline{q^2}}{2} + \frac{\overline{p}}{\rho}$ and $\frac{\overline{\omega^2}}{2}$ are variable with x_2. Assume furthermore that in this case $\overline{u'_2 \left(\frac{q^2}{2} + \frac{p}{\rho}\right)}$ can be written in the form $-l \overline{u_2'} \frac{d}{dx_2}\left(\frac{\overline{q^2}}{2} + \frac{\overline{p}}{\rho}\right)$ and $\overline{u_2' \frac{\omega'^2}{2}}$ in the form $-l \overline{u_2'} \frac{d}{dx_2}\frac{\overline{\omega'^2}}{2}$ where $u_2' = \sqrt{\overline{u_2'^2}}$ and l is a length, analogous to the mean free path of the kinetic gas theory or to the mixing length of *Prandtl's* momentum transfer theory. *Prandtl* tries to connect the mixing length with the geometrical characteristics of the flow problem. He assumes for instance, l proportional to the distance from the wall or in the center of a channel proportional to the width of the channel. The author believes that l must be determined by the local characteristic values of the turbulence such as u_2', λ, ν. Hence, write $l = \lambda f\left(\frac{u_2' \lambda}{\nu}\right)$. Now it is known that $u_2' \frac{q^2}{2}$ is of the order of q^3; hence $l \sim L$. In order that l should be of the same order as L in the case of very large Reynolds numbers, it must be assumed that $f\left(\frac{u_2' \lambda}{\nu}\right)$ behaves like $\frac{\lambda q}{\nu}$ for large values of the argument, or, for instance, as $\nu \to 0$. The simplest assumption satisfying this condition is $l = \text{const.} \frac{\lambda^2 u_2'}{\nu}$. This assumption can be supported by calculating the diffusion coefficient for solid particles suspended in a fluid. The diffusion coefficient corresponds to $l u_2'$ and is equal to const. $\times \frac{m u_2'^2}{\mu d}$ where m is the mass and d the diameter of the particles. If the density of the particles is that of the fluid and the diameter is assumed to be proportional to the eddy dimension λ, the diffusion coefficient

will be const. $\frac{\lambda^2 u_2'}{\nu}$, as assumed above for dimensional reasons. It is assumed that the mixing lengths l for the diffusion of energy and vorticity are equal, or at least proportional.

Homologous Turbulence

In part A the case in which the correlations coefficients of the velocity components and their derivatives are the same in all points of the fluid and invariant with respect to rotation and reflection of the coordinate axes (isotropy) was considered. Isotropy cannot exist in the case of shear motion, because, *e.g.* the mean value $\overline{u'_1 u'_2}$ is different from zero. The next simplest case is that in which the correlation coefficients are not invariant as far as rotation and reflection are concerned, however, they are independent of the location of the point considered. This type of turbulence is called homologous (similar). For this case, for instance, $\overline{u'_1 u'_2}$ will be proportional to $\overline{q^2}$ and expressions like $\Sigma_i \Sigma_k \left(\frac{\partial u'_i}{\partial x_k}\right)^2$ will be expressed in the form

$$\text{const.} \times \frac{\overline{q^2}}{\lambda^2}$$

Homologous turbulence represents a special case even if the type of flow is restricted to that of a parallel mean motion. It is obvious, for instance, that homologous turbulence cannot prevail in the case of the flow between two stationary walls. In the center $\frac{\overline{u'_1 u'_2}}{\overline{q^2}} = 0$ whereas it is different from zero anywhere else; hence, this correlation coefficient is variable with the location of the point considered. Homologous turbulence is a possible assumption for the pure shear motion where the shearing stress is constant across the fluid. This case will be considered in the next section. Because $\tau = -\rho \overline{u'_1 u'_2} = \text{const.}$ $\overline{q^2}$ is independent of x_2 there is no energy transport normal to the mean motion. In other words, the dissipation in every layer of the fluid is equal to the work done by the shearing stress. This is evidently not correct for the flow between stationary walls, because in this latter case energy is dissipated in the center whilst at the same place the work $\tau \frac{dU}{dx_2}$ vanishes.

Flow Between Two Moving Walls (Couette's Problem)

Assume that the fluid is enclosed between two parallel walls at $x_2 = \pm a$ and the two walls are moving parallel to x_1 in opposite directions. A constant shearing stress of the magnitude τ is transferred through the fluid. Then under the assumption of homologous turbulence $\overline{q^2}$ is constant and proportional to $\frac{\tau}{\rho}$. Write $\frac{\tau}{\rho} = k_1 \overline{q^2}$. The energy equation is reduced in this case to

$$\frac{\tau}{\rho} \frac{dU}{dy} = \nu \Sigma_i \Sigma_k \overline{\left(\frac{\partial u'_i}{\partial x_k}\right)^2} \tag{11}$$

Substitute for the right side of the equation $k_2 \nu \frac{\overline{\omega^2}}{\lambda^2}$ and consequently $\frac{dU}{dy} \frac{\lambda^2}{\nu} = \frac{k_2}{k_1}$. The equation for the mean eddy vorticity is given by

$$\frac{d}{dx_2}\left[l u_2' \frac{d}{dx_2} \frac{\overline{\omega'^2}}{2} \right] = \nu \Sigma_i \Sigma_k \overline{\left(\frac{\partial \omega_i'}{\partial x_k}\right)^2} \tag{12}$$

Put $\Sigma_i \Sigma_k \overline{\left(\frac{\partial \omega_i}{\partial x_k}\right)^2} = k_3 \frac{\overline{\omega'^2}}{\lambda^2}$ and substituting in accordance with the section on "Turbulent Diffusion," $l u'_2 = k_4 \frac{\lambda^2}{\nu} \overline{q^2}$,

Eq. (12) becomes

$$\frac{k_4 \overline{q^2}}{2\nu} \frac{d}{dx_2}\left[\lambda^2 \frac{d\overline{\omega'^2}}{dx_2} \right] = \nu k_3 \frac{\overline{\omega'^2}}{\lambda^2} \tag{13}$$

Now substitute $\frac{k_1}{k_2} \frac{dU}{dy}$ for $\frac{\nu}{\lambda^2}$ on both sides of the equation and take into account, that $\overline{\omega'^2} = \text{const.} \frac{\overline{q^2}}{\lambda^2}$. Then a simple calculation leads to the following equation $\Omega = -\frac{dU}{dx_2}$

$$\frac{d}{dx_2}\left[\frac{1}{\Omega} \frac{d\Omega}{dx_2} \right] = 2 \frac{k_1^2 k_3}{k_2^2 k_4} \frac{\rho}{\tau} \Omega^2 \tag{14}$$

An interesting feature of this equation is that the viscosity coefficient does not appear in it; this is in accordance with the known result that the velocity distribution plotted from the center of the channel is independent of Reynolds number and depends only on the shearing stress τ and on the ratio $\frac{x_2}{a}$. The general solution of Eq. (14) is indeed

$$\Omega = \frac{1}{k} \sqrt{\frac{\tau}{\rho}} \frac{\alpha}{\cos(\alpha x_2 + \beta)} \tag{15}$$

where α and β are integration constants and $k = \sqrt{\frac{2k_1^3 k_3}{k_2^2 k_4}}$. Because of symmetry $\beta = 0$; on the other hand $\Omega = \infty$ for $x_2 = \frac{\pi}{2\alpha}$; so that if $x_2 = \frac{\pi}{2\alpha} - \eta$, then for the small values of η

$$\Omega = \frac{1}{k} \sqrt{\frac{\tau}{\rho}} \frac{1}{\eta} \tag{16}$$

and

$$U = \text{const.} + \frac{1}{k} \sqrt{\frac{\tau}{\rho}} \log \eta \tag{17}$$

Hence, the well known logarithmic velocity distribution which exists in turbulent parallel flow near a wall (outside of the laminar sublayer) is obtained. $x_2 = \frac{\pi}{2\alpha}$ is identified with the distance a between center and wall and Eq. (15) is written in the form

$$\Omega = \frac{1}{k} \sqrt{\frac{\tau}{\rho}} \frac{\frac{\pi}{2a}}{\cos \frac{x_2}{a} \frac{\pi}{2}} \tag{18}$$

or integrating (the negative sign at the right side is omitted as irrelevant)

$$U = U_c + \frac{1}{k} \sqrt{\frac{\tau}{\rho}} \log \tan\left[\frac{\pi}{4}\left(1 + \frac{x_2}{a}\right) \right] \tag{19}$$

Eq. (19) gives the complete solution of the problem of the distribution of mean velocity in a parallel shear motion between two walls.

Final Remarks

(a) Eqs. (16) and (117) for the velocity distribution near the wall are in accordance with the results of the semi-empirical theory of turbulence existing at present.[2] In Prandtl's

[2] The present theory of turbulence is presented in an excellent way in the booklet of Bakhmeteff published recently by the Princeton Press.

theory these results follow from the assumption, that the mixing length is proportional to the distance from the wall. However, this assumption is based on dimensional considerations only and no way of computing the distribution of the mixing length over the cross section is given by the theory. The theory of similarity suggested by the present author in 1929 gives a rule for calculating the mixing length; however this rule has an approximate character and is also based on dimensional considerations. In the present theory the equation which determines the distribution of the mixing length is based on a definite physical picture of the mechanism of turbulence.

(b) The assumption of similar turbulent flow pattern suggested previously by the author gives an exact mathematical formulation in virtue of the definition of homologous turbulence. As a matter of fact, strict similarity of the actual motion is too severe a restriction, and can hardly be expected to exist in regions of finite extent. Defining homologous turbulence by the feature that the correlation coefficients are independent of the location of the point considered, statistical similarity is substituted for the similarity of the actual instantaneous flow pattern.

(c) The universal constant k introduced first in the present author's theory of mechanical similarity and turbulence appears in the new theory composed of a number of constants. However, while in the old theory no reason was given for any particular value of k each of the constants of the new theory has a definite physical significance. Although one is not yet able to determine their numerical value, they are exactly defined by some physical process. As far as their approximate magnitude is concerned, the following consideration is quite interesting.

According to the new theory $\frac{dU}{dx_2}\frac{\lambda^2}{\nu} = \frac{k_2}{k_1}$. On the other hand near the wall $\frac{dU}{dx_2} = \frac{1}{k}\sqrt{\frac{\tau}{\rho}}\frac{1}{\eta}$ (Eq. (16), hence, $\frac{\lambda^2}{\nu} = \frac{k_2}{k_1}\frac{k\,\eta}{\sqrt{\tau/\rho}}$. The mixing length is defined by $lu_2' = k_4\frac{\lambda^2}{\nu}\bar{q}^2$, hence, $l = \frac{k_4 k_2 k}{k_1^2}\frac{\sqrt{\tau/\rho}}{u_2'}\eta$ and substituting the value of k_4 from $k^2 = \frac{2k_3 k_1^3}{k_2^2 k_4}$, we find

$$l = 2\frac{k_3}{k_2}\frac{k_1}{k}\frac{\sqrt{\tau/\rho}}{u_2'}\eta \qquad (20)$$

The ratio k_3/k_2 is known in the case of isotropic turbulence; it is equal to λ^2/λ^2_w. As for the ratio $\lambda^2/\lambda^2\omega$ the value 3/2 corresponds to the linear law of decay of turbulence which is in fair accordance with experiments. This value is used in the following approximate estimate of l. The constant k_1 and the ratio $\sqrt{\tau/\rho}/u_2'$ are not known for the case of pure shear motion; however, there is experimental evidence for the ratio $\sqrt{\tau/\rho}/u_1'$ in the case of two dimensional mean motion between fixed walls. Assuming that the conditions are similar in both cases near the wall, put $\tau/\rho u_1'^2 \cong 0.3$ and $\overline{u_1'^2} = \overline{u_2'^2} = \overline{u'^2} = \overline{q^2}$. This corresponds roughly to Wattendorf's experimental results.[3] Finally $k \cong 0.4$. Then Eq. (20) yields the result, that $l = 0.41\eta$.

This value for the mixing length is in close accordance with the value l_{Pr} obtained in Prandtl's theory putting $\frac{\tau}{\rho} = l^2_{Pr}\left(\frac{dU}{dx_2}\right)^2$ However, it seems that the coincidence is rather incidental, because the definitions of the two mixing lengths are entirely different. Since $\frac{dU}{dx_2} = \frac{1}{k}\sqrt{\tau/\rho}\frac{1}{\eta}$ the "exchange coefficient" $\frac{\tau}{\rho}\Big/\frac{dU}{dx_2} = k\sqrt{\frac{\tau}{\rho}}\eta$. Compare this value with the exchange or diffusion coefficient being used in the new theory for the diffusion of mean eddy vorticity. This coefficient is equal to lu_2' or according to the calculation above

$$\epsilon = .41\,\eta\,u_2'. \quad \text{With } u_2' = \frac{\sqrt{\tau/\rho}}{\sqrt{0.3}}, \epsilon = .75\sqrt{\tau/\rho}\,\eta.$$

Hence, the actual momentum transfer is roughly half of the amount which would correspond to the diffusion coefficient of the mean vorticity.

(d) The new theory gave a complete solution of the case of homologous turbulence. In every other case at least one additional assumption is necessary, *e.g.* concerning the correlation coefficient $-\frac{\overline{u_1'u_2'}}{\bar{q}^2} = \frac{\tau}{\rho\bar{q}^2}$. If $\frac{dU}{dx_2} = 0$, $\frac{\tau}{\rho\bar{q}^2} = 0$; if the turbulence is homologous, a definite constant value of $\frac{dU}{dx_2}\frac{\lambda^2}{\nu}$ corresponds to $\frac{\tau}{\rho\bar{q}^2}$. Combining these two cases, the simplest plausible assumption is that $\frac{\tau}{\rho\,\bar{q}^2}$ is proportional to $\frac{dU}{dx_2}\frac{\lambda^2}{\nu}$. It is planned to use this assumption and to try to extend the theory to the case of parallel mean flow between fixed walls, to flow through convergent and divergent nozzles, to curved flow and related problems. Furthermore, it is planned to check experimentally the results which can be deduced from the theory of homologous turbulence especially those concerning the distribution of the intensity $\bar{q}^2$ of the fluctuations and the distribution of the eddy dimension λ.

[3] F. L. Wattendorf, *Investigations of Velocity Fluctuations in a Turbulent Flow*, Journ. of Ae. S., Vol. 3, No. 6.

Dollar Values in Airplane Design

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Summary

THIS paper explains the application of a partially rationalized method of reaching decisions relating to the general and detail design of an airplane. The method consists basically of assigning, by means which are explained and illustrated, dollar values to differences of weight, differences of speed, etc., which influence design, in order that all such factors may be reduced to common terms. It is shown how this method permits relatively accurate determination of ideal characteristics needed to meet given requirements, and an example is given showing how a typical design problem, involving the determination of the ideal wing span, may be solved.

Introduction

It is the purpose of this paper to present a method whereby some of the design decisions made during the development of an airplane may be partially rationalized rather than be left solely to the unaided judgment of the designer. No problem having as many aspects, both measurable and unmeasurable, as do most aircraft design problems, can be expected to submit completely to any quantitative rationalization but in many cases a systematic means of making more accurate decisions will be found helpful in achieving a more nearly ideal design.

Every new airplane design, is, or should be, intended to meet some particular combination of requirements. In the case of air transports or machines intended for the government services most of these requirements are more or less completely itemized in the procurement specifications, but even in the case of private or commercial machines the requirements are just as definite except that they must be drawn up by the manufacturer. In general the design which most nearly meets the particular requirements involved is considered the best and to accomplish this is the chief function of the designer. His ability to do so depends primarily upon four things: knowledge gained thru training and experience; ability to apply knowledge with good judgment; resourcefulness; and the amount of time available. The methods proposed are to serve as an aid to judgment and to replace opinion with fact wherever feasible. They can be used to any extent consistent with the time which is available and justified.

The Method

Every feature of a new airplane design presents a problem, or series of problems. The size, shape, type, arrangement, number used, and materials for major units and all their details must be decided and decided carefully, because after the design has passed the first stage and "frozen", changes are difficult and costly. Each of the considerations mentioned is chiefly important as it affects one or more of the following characteristics of the completed airplane: (a) Useful load (or pay load for a given range). (b) Operating speed (effective in service). (c) Supplementary performance characteristics. (d) Overall safety. (e) Sales price. (f) Operating cost (including maintenance, fuel and oil consumption, depreciation, repair, overhaul, insurance, etc.). (g) Factors such as reliability, strength, rigidity, freedom from vibration, and proper functioning which are, of course, essential. (h) Factors such as accessibility, replaceability, comfort, roominess, appearance, simplicity of control, and general suitability which must be given as much consideration as possible.

Ordinarily not one but many of these factors are involved in any design problem and, since they seem to be invariably antagonistic toward each other, some kind of compromise is usually called for. The problem then becomes a question of where to lay the emphasis and how much weight to assign to the effect of each of the pertinent factors. Here judgment or common sense are ordinarily relied upon, but a *more nearly ideal decision can be made if some relative value is assigned to each factor and the choice is allowed to rest on the solution giving the greatest total value.* This requires that some standard of values be set up and it is proposed to discuss this method and the means of establishing these values.

For military designs the point system of evaluation is sometimes used since the sales price and operating cost are not given the relative emphasis in military procurement that they are in civil procurement. In such a system an arbitrary maximum number of points is assigned to each of the important characteristics, such as the following: (1) High speed. (2) Operating speed. (3) Endurance. (4) Pay load. (5) Time to climb to a specified altitude. (6) Service ceiling. (7) Distance required to take off and land over a given

obstacle. (8) Structural design. (9) Power plant and equipment installations. (10) Maintenance and repair considerations. (11) General utility for the intended purpose.

In the case of the first seven characteristics, which have numerical values, a minimum acceptable figure and a maximum desired figure are established and points are then assigned for each characteristic in proportion to the relation of the actual value to the minimum and desired values.

In the case of the other characteristics, which do not have numerical values, each one is subdivided as much as feasible and some portion of the maximum number of points is usually assigned to each of the subdivisions by a committee, after examination of the airplane.

Thus, providing that cost is not a first consideration and that the original maximum number of points assigned to each characteristic corresponds to the actual requirements of the service to which the airplane is to be put, then the value of a completed airplane, or at least the relative value of several similar completed airplanes, can be fairly accurately determined. This method, which is simply a rationalization of the older method of deciding on the relative merits of competitive airplanes, is obviously an improvement over unaided judgment. Its application has, however, usually been confined to a comparison between machines already built, whereas *it would be far more valuable as a guide to design decisions relating to machines not yet begun.* It also leaves room for considerable margin of error in the assignment of the original points since they cannot be determined on the basis of operating cost or profit as they could in the case of commercial machines.

Any system of unit values can be used. Those most obvious are merit points, pounds, miles per hour, and dollars, each of which has certain advantages. The dollar is used here for the following reasons:

(1) The dollar is a unit whose use and significance is generally familiar and understood.

(2) The relative dollar value of a given change or alternative is not likely to be confused with other values expressed in the same unit.

(3) Results, as applied to commercial design seem tangible, and are determined directly by means of the same units in which they are to be finally expressed.

The first step is to determine the values to be assigned to those characteristics which lend themselves to quantitative evaluation. For a given design it should be only necessary to determine these values once and they can be thereafter used for all subsequent calculations. They can also be used for other similar designs having like requirements, so that some complication in the basic calculations seems justified. The first step is the estimation of sales price which should generally be based on the manufacturing cost.

Estimation of Manufacturing Costs

Obviously it is impossible to discuss all the factors making up the manufacturing cost or the sales price of an airplane. However, because of the approximate nature of the results required and the undeveloped state of the method, precision is not needed and an approximate empirical method of cost determination will suffice.

The manufacturing price of an airplane is ordinarily broken down in approximately the following manner:

M = Cost of materials (or of raw materials only)

P = Cost of engines, standard accessories, propellers, and instruments (or of all purchased fabricated materials)

L = Cost of direct labor

B = Cost of factory overhead (Burden) (usually considered a function of the cost of direct labor)

D = Cost of development (total of design cost, special tooling cost and loss on the experimental machine, distributed over the anticipated number of machines)

Material cost, which will be assumed to include both raw materials and purchased parts, exclusive of engines, standard accessories, propellers and instruments, depends primarily upon the kind of materials used, the proportion of wastage, the quantities ordered at one time, and the vendor's price level at the time of purchase. To simplify calculation it is assumed that the wastage is a constant proportion of the material used, that the quantities ordered at one time are proportional to the number of machines being built, that the price level remains constant, and that the weight of materials used (exclusive of engines, etc.) is the same proportion of the empty weight of any airplane, and these assumptions do not introduce errors which seriously affect the results for the purpose at hand. An equation for the material cost of one machine can now be simply written:

$$M = w\, c_m$$

The symbols used are tabulated in the list below.

It has been found in practice that material and labor costs shrink as the production quantities increase, and that *on the average* the relationship is approximately logarithmic, so that a factor of $1/q^n$ can be applied. Thus the approximate material cost becomes:

$$M = w\, c_m/q^n$$

The cost of purchased parts such as engines, accessories, propellers and instruments is more nearly a function of rated brake horsepower than of empty weight. The cost of such material does not change appreciably with the quantity purchased because the number used by any one airplane manufacturer does not usually greatly affect the total quantity of such units manufactured. The cost of purchased parts is therefore expressed as:

$$P = p\, c_p$$

Direct labor costs, like material costs, seem to bear a surprisingly close relationship with empty weight, and the correction for quantity can be similarly applied. Thus the labor cost is expressed as:

$$L = w\, c_e/q^x$$

Factory overhead determination is very complex if calculated precisely, so that it is customary to consider it as a fixed proportion of the cost of direct labor, and this can be written:

$$B = L\, b$$

Development cost which is assumed to include the cost of engineering, the cost of special tools and the loss on the experimental airplane, is likewise complex if precision is attempted, but fortunately it bears a fairly close relationship with production cost for most airplane types. Naturally the proportion of total development cost assigned to each production machine depends directly upon the number of machines to be made. For simplicity it is therefore assumed that the total cost of development is distributed over the same number of machines as the production quantity assumed for the particular calculation involved. If this number of machines has already been completed and an additional lot is under consideration, then the development cost has presumably been written off and only a relatively small allowance need be made for current design changes. The development cost per airplane can then be written:

$$D = (M + P + L + B)\, r/q$$

Sales expense and manufacturing profit are purposely omitted from this discussion because these can be easily handled for a particular case, but have not yet been stabilized sufficiently to make a reasonable generalization possible.

When these factors are all combined, the approximate expression for the total manufacturing cost of an airplane becomes:

$$\text{Manufacturing cost} = (M+P+L+B)\,(1 + r/q) = [w\, c_m/q^n + p\, c_p + (w\, c_e/q^x)\,(l + b)](l + r/q)$$

The variables used are as follows:

p = Total rated brake horsepower (bhp.).
q = Number of machines built in one lot.
w = Complete empty weight of airplane (lbs.).

The factors used must be established for the particular type and purpose of the airplane, the characteristics of the production factory, and other conditions. These factors, together with suggested values, are given in Table 1.

If the values for the constants are chosen carefully, prices of ample accuracy can be obtained. The method could, if desired, be also used in establishing sales prices on the basis of an assumed quantity production because the relation between cost, quantity and sales price are sometimes such that the exact price set for a given model is not particularly critical. In another sense this method might be used as a rough gauge of overall organization efficiency because the organization which could build machines at less than the computed cost would, in general, be more efficient than one whose costs were over those calculated.

As an example assume a proposed airplane is to be of a conventional all-metal transport type having an empty weight of 7500 lbs., a total rated power of 840 b.hp., seating for 8 passengers, and anticipate that a lot of 75 machines will be built in continuous production. The manufacturing cost can be estimated as follows based on average assumptions:

$$\text{Manufacturing cost} = [(7500)\ (1.2)/75^{.075} + (840)\ (15.0) + (7500 \times 5.60/75^{.80}) \times (1 + .90)]\ (1 + 5.0/75) = \$43{,}700.00$$

Total sales price assumed for complete airplane = \$48,000

Cost of engines, accessories, propellers, & instruments $= 840 \times 15.0 = \$12{,}600$

Net cost of airplane less engines, etc., to purchaser = \$35,400

Estimation of Operating Cost

For the purpose of determining operating costs airplanes should be divided into three distinct categories; private or commercial, transport, and military. Each of these presents a somewhat different problem of operating cost determination. The costs themselves can also be divided into direct or flying costs, and indirect or overhead costs. The former can, under known conditions, be calculated with rather good accuracy, while value of the latter is open to considerable error of assumption and interpretation, varying considerably among different operating organizations. However, since the indirect costs are almost independent of the design characteristics of the airplane they need not be considered here. In Table 2 the factors making up direct operating costs for each of the three categories is given and suggested coefficients are included where necessary. The figures shown for the transport category can be considered the most accurate because more study has been given to these than to the others, and much more information is available. The figures for military operation are rough estimates only because of the almost complete absence of reasonable looking information available on this subject. The figures suggested relative to private and commercial airplanes will be found to disagree with most owners' estimates because each has his own methods of calculating and many do not include such items as insurance or insurance reserves, and consequently do not reflect true costs. The values shown should, however, lead to a sufficiently true estimate of direct costs for the present purpose.

TABLE 1

Suggested Values for Constants

Symbol	Assumed Constants	Suggested Values		Notes on Special Conditions and Circumstances
		Commercial Production	Military or Transport Production	
b	Approximate ratio of factory overhead to direct labor (%).	50	70	Small ratio of plant to production
		90	110	Large ratio of plant to production
c_e	Approximate cost of labor for 1 airplane per lb. empty weight (\$/lb.).	4.20	5.60	All metal construction
		1.50	2.00	Steel tube and fabric cover construction
c_m	Approximate cost of all materials except engines, etc., for one airplane, per lb. empty weight (\$/lb.).	1.10	1.20	All metal construction
		.90	1.10	Steel tube and fabric cover construction
c_p	Approximate cost of engines, accessories, propellers and instruments per rated b.hp. (\$/b.hp.).	13.5	15.0	Controllable pitch propellers
		12.5	14.0	Adjustable pitch propellers
s	Labor — quantity exponent.	.30	.30	
n	Material — quantity exponent.	.075	.075	
r	Approximate ratio of total development cost to production cost per airplane	4.5	5.0	All metal construction
		2.5	3.5	Steel tube and fabric cover construction

The direct cost per mile of operating is found by totalling the costs per hour and dividing by the block-to-block speed. This speed is not the cruising speed but is considerably less because of necessary allowances for maneuvering time on the ground, takeoff and landing time, and net time lost in climbing to and descending from the operating altitude under actual flying conditions. For short flights the reduction in effective speed resulting from these time losses is well over 10% of the total time so that this speed correction should always be made.

For the previous example the direct operating cost per hour will be estimated. It is assumed that the resale value of airplane and engine is 10% of the original cost, that the economic life of the airplane is 8,000 hours, that the effective life of the engines, propellers, etc., is 3,000 hours, that the average cruising power is 500 b.hp., that the cost of fuel is .13 dollars per gallon and oil is .40 dollars per gallon, that the overall cruising fuel consumption is 45 gal./hr. and overall oil consumption is 2 gal./hr., and that the average salary of the crew is 10 dollars/hr. The calculation is made in Table 3.

If it is now assumed that the average block-to-block speed which can be made by the machine under investigation operating over a given route is 175 m.p.h., then the direct operating cost per mile is simply 36.95/175=.211 \$/mile, and is .211/8=.0264 \$/seat-mile. As an additional step, if it is assumed that the average load carried is 57% of the capacity, then the direct operating cost per passenger-mile becomes .0264/.57=.0463 \$/passenger-mile.

ESTIMATION OF THE VALUE OF SAVING WEIGHT

If weight can be saved in the structure or equipment of an airplane it is always desirable to do so,

TABLE 2

Methods of Estimating the Operating Cost Per Hour ($/hr.)

Category	Private and Commercial*	Transport	Military
Depreciation — airplane less engines, etc.	$\frac{\text{Airplane cost less engine cost, etc., less resale value}}{\text{Number of hours flown}}$	$\frac{\text{Airplane cost less engine cost, etc., less resale value}}{\text{Number of hours flown}}$	$\frac{\text{Airplane cost less engine cost, etc.}}{\text{Number of hours flown}}$
Depreciation — engines, accessories, props, and instruments.	$\frac{\text{Cost less resale value}}{\text{Number of hours run}}$	$\frac{\text{Cost less resale value}}{\text{Number of hours run}}$	$\frac{\text{Cost}}{\text{Number of hours run}}$
Fuel and oil.	(cost/gal.) (gal./hr.)	(cost/gal.) (gal./hr.)	(cost/gal.) (gal./hr.)
Maintenance, repair and overhaul of airplane less engines, etc.	(.00008) (Cost of airplane less engines, etc.)	(.00009) (Cost of airplane less engines, etc.)	(.00015) (Cost of airplane less engines, etc.)
Maintenance, repair and overhaul of engines, accessories and propellers.	(.008) (Aver. cruis. b.hp.)	(.0095) (Aver. cruis. b.hp.)	(.012) (Aver. cruis. b.hp.)
Insurance or reserve for airplane, including fire, theft, windstorm, crash, etc.	(.0004) (Cost of complete airplane)	(.00005) (Cost of complete airplane)	(.0001) (Cost of complete airplane)
Insurance or reserve for passenger liability, property damage, etc.	(.20) (Number of passenger seats)	(.15) (Number of passenger seats)	—
Crew salary and insurance.	(1.20) (Aver. crew salary/hr.) **	(1.10) (Aver. crew salary/hr.)	(1.15) (Aver. crew salary/hr.) **

* Note that storage, pilot's expenses, etc., are omitted because these should be considered indirect costs.
** These could frequently be omitted.

TABLE 3

		$/hr.
Depreciation of airplane — less engines, etc.	(35400 × .90)/8000	= 3.98
Depreciation of engines, Acces., Props., & Instruments	(12600 × .90)/3000	= 3.78
Fuel	(.13) (45)	= 5.85
Oil	(.40) (2)	= .80
Maintenance, etc.— Airplane less engines, etc.	(.00009) (35400)	= 3.19
Maintenance, etc.— Engines, Acces., Props., & Instr.	(.0095) (500)	= 4.75
Insurance — Airplane	(.00005) (48000)	= 2.40
Insurance — Liability, etc.	(.15) (8)	= 1.20
Crew Salary & Insurance	(1.1) (10.0)	= 11.00
Total Direct Operating Cost per hour		= 36.95

providing, however, that other characteristics of the airplane, such as cost, performance, or comfort are not too adversely affected. If it is assumed that a given proposed change is of such nature that only the weight and costs are influenced then it will be possible to estimate the net dollar value of the change and therefore whether or not the change should be made. In order that the performance remain unchanged, the power and gross weight must be constant and any increase or decrease in empty weight must decrease or increase the useful load, and provision for useful load, by a corresponding amount. Then, since the range and the crew weight are not altered, all the weight saving or loss is reflected directly in altered pay load (and provision for pay load). The problem is now simply one of estimating the additional value due to increased payload, or reduction in value due to decreased payload.

This can probably be done most easily and accurately in the case of airline transport machines, where the major criterion of operative efficiency is the difference between operating income and operating costs. In this case it can be assumed that on the average the number of passenger-miles and the average number of mail and express ton-miles of operation per year, are the same regardless of differences in the capacities of the individual machines being operated. Thus, providing that suitable schedules are possible in all cases, and that passenger appeal is equal, the ability to carry 10% more payload per airplane, would make it possible to carry the airline operating load with only 1/1.10=91% as many airplanes. From another viewpoint, if the number of airplanes were kept the same then the average load carried on each trip could probably be almost correspondingly increased, because higher maximum loads could be accepted.

On the basis of the former hypothesis and using the airplane originally assumed as an example, it is possible then to estimate the dollar value of such a change. *Care must be taken that the added or reduced value to the operator is not confused with that to the manufacturer,* because when the airplane is sold the full additional value to the weight which has been saved, obviously cannot be entirely added to the sales price. Furthermore, if extra weight savings are made in the design they will increase the manufacturing cost and hence the sale price so that the net value of the savings to the operator will depend upon how much more he is required to pay for the equipment.

In Table 4 an estimate is made for the number of 8 and 9 passenger machines which would be required on a hypothetical airline having a potential traffic of 16,000,000 passenger-miles per year. The additional assumptions are made that the average passenger loading is 57% and that machines will be operated on an average of 1600 hours per year.

TABLE 4

Estimated number of passenger miles per year	=	16,000,000
Number of seat miles per year required at 57% average load = 16,000,000/.57	=	28,000,000
Number of 8 passenger airplane miles required per year = 28,000,000/8	=	3,500,000
Number of 8 passenger airplane hours required at 175 m.p.h. speed = 3,500,000/175	=	20,000
Estimated normal number of hours per year each airplane will be operated	=	1,600
Average number of 8 passenger airplanes required at 175 m.p.h. = 20,000/1600	=	12.50
Average number of 9 passenger airplanes which would be required at 175 m.p.h. = (12.50) (8)/9	=	11.11
Average number of 8 passenger airplanes required at 185 m.p.h. = (12.50) (175)/185	=	11.82

The designer now has the alternative of leaving the eight seat arrangement unchanged, or of changing the capacity to nine passengers, if that much change is technically feasible by means of more refined design. First, he can, by adjusting the expenditure of money and time on the development and construction of the airplane, so change the empty weight that the gross weight and power can remain the same as before. Of course the more empty weight is reduced, the greater is the cost of additional weight saving so that this method is limited to the point where the additional cost of weight saving is just balanced by the additional sales price, which can be commanded because of that saving. Second, he can simply readjust the size, weight, and power of the entire machine, in which case its operating cost will change approximately in proportion to the change in payload. As can be shown, this latter method in general offers no advantage whatsoever, from the standpoint of direct operating cost, unless by so doing the proportion of weight and expense of the crew is reduced, or that some particular operating requirement can be more satisfactorily met.

An estimate based on the first method, has therefore been made. If sufficient space is available in the fuselage an extra passenger, or an equivalent weight of other payload, can be carried by providing an additional seat, and other passenger equipment or the additional cargo compartment capacity. It is estimated that the weight of such additional accommodation including additional soundproofing, upholstery, etc., will be of the order of 100 pounds so that a total weight saving in structure and equipment required to allow the addition of one passenger with his baggage will be approximately 300 lbs.

In Table 5 various values are chosen to represent additional sales prices required if enough weight to permit an additional passenger is saved. The added value of the airplane to the operator under these conditions as reflected in reduced direct operating costs is then determined. Maintenance costs are increased with first cost because maintenance is usually more difficult with lighter structure. Value per pound saved to the operator is then plotted against the additional manufacturing cost for various values of airplane life in Fig. 1.

TABLE 5

Estimation of Dollar Value of Weight Saved, to the Operator, as a Function of the Additional Cost Involved ($)

Additional price of airplane because of additional passenger.	Basic Design	9 Passengers		
		0	10.000	20.000
Additional price per pound added	—	0	33.33	66.67
Sales price	48,000	48,000	58,000	68,000
Sales price, less engines, etc.	35,400	35,400	45,400	55,400
Depreciation of airplane less engines, etc. per hour	3.98	3.98	5.10	6.23
Maintenance, etc., airplane, less engine, etc	3.19	3.19	4.01	4.98
Insurance, airplane, etc	2.40	2.40	2.90	3.40
Insurance, liabilities, etc	1.20	1.35	1.35	1.35
Other operating costs (unchanged)	26.18	26.18	26.18	26.18
	36.95	37.10	39.54	42.14
Direct operating cost per mile	.2111	.2120	.2264	.2408
Direct operating cost per seat mile	.02639	.02355	.02515	.02675
Direct operating cost per year (all airplanes)	738,920	659,540	704,340	749,140
Saving per year — total	—	79,380	34,580	—10,220
Savings per year — each of 11.11 airplanes	—	7,145	3,112	—920
Savings per year per pound — each airplane	—	23.81	10.37	—3.07
Total savings per pound — 5 year life	—	119.05	51.85	—15.35

It now becomes obvious that the potential savings made possible by saving weight should properly be divided between the manufacturer and the operator. The selection of a particular value is a matter of judgment applied to an individual case and any value between the maximum of one and the maximum of the other may be chosen for a particular assumed economic airplane life.

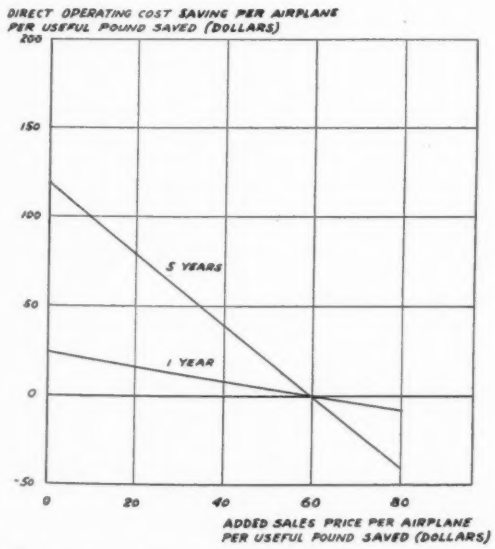

FIG. 1. The value of weight saved—Typical chart showing dollar savings to the operator per pound saved, in terms of additional first cost per pound saved. (Providing that power and gross weight are unchanged.)

It should be borne in mind that the values used are a sample estimate only and would not apply to any conditions differing from those assumed. For example, the value of additional payload increases in direct proportion to the block-to-block speed of the airplane approximately as shown in Fig. 3, and it is not by any means a constant. The method, is, however, general, and will be found as accurate as the assumptions with which it is used. Of course, it is frequently not feasible to save enough weight to allow for an extra passenger, but, since the revenue derived from express is approximately the same per pound as that from passengers, any part of this weight saving should be proportionately advantageous. *In the example cited it would seem reasonable for the manufacturer to spend an amount corresponding to a $20.00 increase in sales price per airplane for each additional pound which he could save in his proposed design.*

ESTIMATION OF THE VALUE OF ADDED SPEED

Increasing the block-to-block speed of an airplane has two direct and important advantages. One of them is the increased value to the passenger, who can save additional time by traveling in a faster machine. This value is, in the case of airlines, reflected in the increased revenues received either thru higher fares per passen-

TABLE 6

Estimation of the Dollar Value of Increasing Speed, to the Operator, as a Function of the Additional Cost Involved ($)

Additional price of airplane because of 10 m.p.h. speed increase.	Basic Design (175 m.p.h.)	(185 m.p.h.)		
		0	5,000	10,000
Assumed additional manufacturing cost	—	0	4,000	8,000
Sales price	48,000	48,000	53,000	58,000
Sales price, less engines, etc	35,400	35,400	40,400	45,400
Depreciation of airplane, less engines, etc., per hour	3.98	3.98	4.54	5.10
Maintenance, etc., airplane, less engines, etc	3.19	3.19	3.64	4.09
Insurance, airplane, etc	2.40	2.40	2.65	2.90
Other operating costs (unchanged)	27.38	27.38	27.38	27.38
Total direct operating cost per hour	36.95	36.95	38.21	39.47
Direct operating cost per mile	.2111	.1997	.2065	.2133
Direct operating cost per seat mile	.02639	.02496	.02581	.02666
Direct operating cost per year — all airplanes	738,920	698,880	722,680	746,480
Saving per year — total	—	40,040	16,240	—7,560
Saving per year — each of 11.82 airplanes	—	3,387	1,374	—639
Saving per year per m.p.h. — each airplane	—	338.70	137.40	—63.90
Total savings per m.p.h. — 5 year life	—	1,693.50	687.00	—319.50

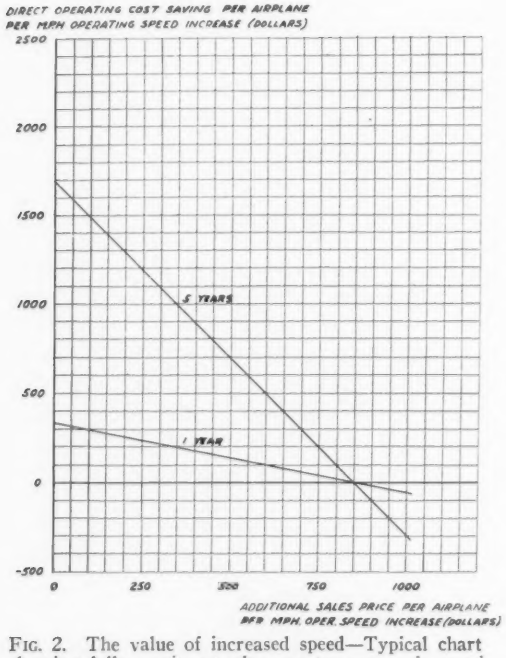

FIG. 2. The value of increased speed—Typical chart showing dollar savings to the operator per m.p.h. speed increase, in terms of additional first cost per m.p.h. increase. (Providing that power and gross weight are unchanged.)

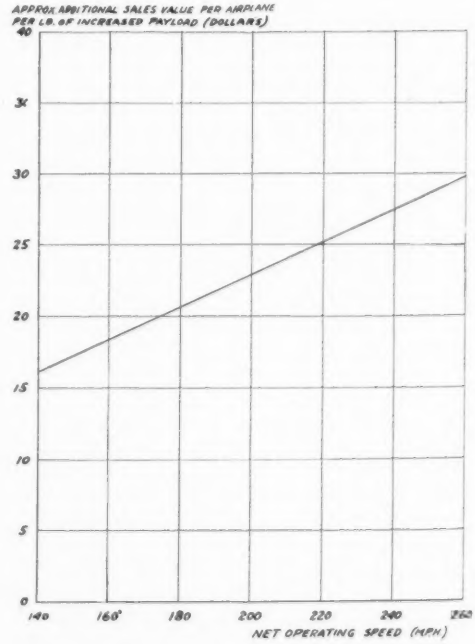

FIG. 3. Approximate additional sales value per airplane for each pound increase in payload attained for various net operating speeds.

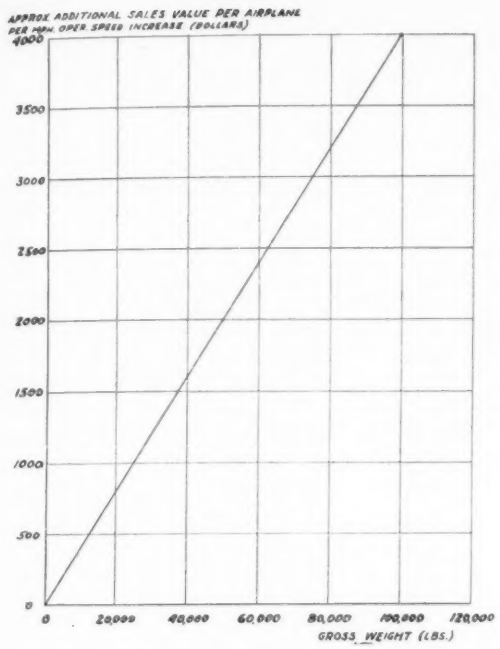

FIG. 4. Approximate additional sales value per airplane for each m.p.h. increase in operating speed attained, for various gross weights.

ger mile, or by increased traffic at the same fare. The other advantage is the increased number of miles covered by each airplane during a given period or during its life. This is reflected in reduced direct operating costs per passenger mile.

The additional fare which may be charged because of greater speed without reducing patronage is almost impossible to estimate. Actually fares have been slowly reduced, and speed has been rapidly increased, and as a result of these and other causes the airline traffic has grown remarkably. Unfortunately there is no way to estimate the influence of each without suitably corrected airline statistics so that it will be necessary to omit this factor from the estimate, although it should be kept in mind in making the final selection of a value for speed increase.

The effect of increased speed upon operating cost can be determined in a manner comparable with that used for weight. It is assumed that the block-to-block speed over a given route can be increased from 175 m.p.h. to 185 m.p.h., by improved aerodynamic cleanness, with certain increase in first cost, but without change in other characteristics such as weight or power. The fact that improved aerodynamic cleanness frequently results in more difficult maintenance, seems to indicate that this cost should continue to be proportional to first cost. Such an estimate is made in Table 6 and the results are plotted in Fig. 2.

The saving which is made possible by increasing the block-to-block speed, should, like weight saving, be properly divided between the manufacturer and the

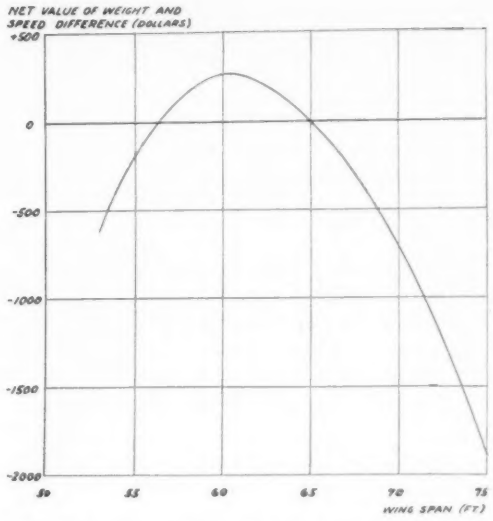

FIG. 5. Determination of the optimum wing span on the basis of weight and speed balance.

operator. When it is remembered that in addition to the savings estimated, a faster machine will attract more patronage at the same fare, it seems that the division should be so placed as to favor the manufacturer so that *it might be worth his while, in the case of the example cited, to spend an amount corresponding to as much as $500 increase in sales price per airplane, for each m.p.h. which he can add to the block-to-block speed of his proposed design.* This applies only to the example used and is not a constant since it varies in approximate proportion to the payload of the machine as shown in Fig. 4.

EVALUATION OF OTHER AIRPLANE CHARACTERISTICS

The other general characteristics of the airplane do not lend themselves nearly so nicely to quantitative evaluation, but can nevertheless often be assigned approximate values, if desired. Appearance for example, is an indefinite factor, but by comparing the sales price of an airplane of one type with that of a different type having a similar sales volume and other characteristics in common, a rough value can be found. Frequently some one having experience in airplane sales work, can make a remarkably close estimate of the dollar value of such characteristics. Thus in making a decision regarding the use of a cantilever, or an externally braced wing, one of the considerations would be the superior appearance of the former and in a particular case, this factor could probably be calculated with sufficient accuracy for the purpose.

APPLICATION TO DESIGN

Perhaps the application of the proposed methods may best be pointed out by the use of a single example. Following is a typical general design problem always

TABLE 7

Wing Span (feet)	55	60	65 Basic Assumption	70	75
Estimated weight of wing (lbs.)	1,440	1,479	1,525	1,578	1,638
Estimated weight of remainder of airplane, empty (lbs.)	5,945	5,960	5,975	5,990	6,005
Total empty weight (lbs.)	7,385	7,439	7,500	7,568	7,643
Weight saved (lbs.)	115	61	—	—68	—143
Estimated operating speed (m.p.h.)	168.9	172.5	175.0	177.0	178.4
Operating speed increase (m.p.h.)	—6.1	—2.5	—	2.0	3.4
Value of weight difference ($) (at 25 $/lb.)	2,875.00	1,525.00	—	—1,700.00	—3,575.00
Value of speed difference ($) (at 500 $/ m.p.h.)	—3,050.00	—1,250.00	—	1,000.00	1,700.00
Net value of weight and speed difference	—175.00	275.00	—	—700.00	—1,875.00

encountered in proportioning any new airplane, in which it is desired to find the optimum wing span. The method can, of course, be used for detail as well as general design. The data for the previously assumed airplane are used.

The landing speed or distance needed for landing or takeoff, the estimated weight, and the type of wing section and flap used, determine the approximate wing area required. This area can be obtained with a large span and small chord or with a small span and large chord. The former leads to higher weight but increased speed, so that it is necessary to combine these two factors in making an exact decision. In Table 7 several values of wing span have therefore been arbitrarily chosen, and the dollar value of the difference in weight and speed is added to determine the optimum. When these values are plotted against the span values used, as in Fig. 5, the optimum span, which in this case is approximately 60 feet, is immediately evident. Of course other factors, such as maneuverability or hangar space requirements, may also have to be considered in a particular case, but having the optimum figure based on weight and speed, the penalty paid for any deviations from this is obvious and the designer can proceed with more assurance that the best possible value is being used.

By intelligent application of the method proposed to those design problems depending upon airplane characteristics which can be numerically evaluated, it is believed that much progress can yet be made toward the goal of optimum design.

Book Reviews

Elements of Practical Aerodynamics, by BRADLEY JONES; John Wiley & Sons, Inc., New York, 1936; 398 pages, ill., $3.75.

Professor Jones explains in the Preface to his book that although there were many books available on aerodynamics none seemed to have been primarily written with classroom use in view, and to fill this need the present volume had been compiled. The fundamentals of aerodynamics have been clearly outlined in simple terms, comprehensible to those students who are first being introduced to the subject of aerodynamics and, in fact, to aeronautics in general.

The text is interspersed with numerical examples and with problems, the answers to which are printed in an appendix. About one-third of the volume is devoted to aerodynamics, starting with a description of the properties of air and then going into the dynamics of airflow with a conventional study of reactions on inclined bodies and airfoils, resultant induced drag, parasite drag, etc.

There follow chapters briefly outlining the bare essentials of the design of aircraft engines, propellers, control surfaces, and instruments, with other chapters dealing with maneuvers, unconventional types of aircraft, materials, and navigation. The final chapter deals with aerostatics in order to complete the student's general knowledge of aeronautics and the book is concluded with an appendix giving standard nomenclature.

T. P. WRIGHT
Curtiss-Wright Corporation

The Boys' Book of Model Aeroplanes, by FRANCIS A. COLLINS; D. Appleton-Century Company, New York; 1936, 262 pages, ill., $2.00.

For many years this book has been a standard volume in the field. It has been completely revised and brought up-to-date in this third edition. While it has little interest for the designer of full scale aircraft it will provide answers to the many questions that are asked by the young generation which is so keenly interested in the construction of models. The simple and concise directions for the designing and construction of model airplanes, its complete survey of all aspects of the subject and its interesting illustrations make it a valuable book for all the young folks who are using this hobby as a means of laying a groundwork for a career in aeronautics when they are older.

The Behavior of Bowed Columns With Intermediate Elastic Supports

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(Received October 30, 1936)

THE theory of the influence of the stiffness of regularly spaced elastic intermediate supports upon the stability limit of straight columns has been treated by various authors. It has been extended to embrace the case of one "jury strut" at a station other than mid-length with and without initial eccentricity, and for these cases the theory has been checked by experiments with two parallel compressed columns connected by a tie.[1]

A general theory for the initially cambered column with several intermediate elastic supports can be developed as suggested in reference 2. A rough approximation can also be obtained by approximating the elastic line by a portion of a sine wave. The formulae thus resulting for the cases of one and two equal supports are given in an appendix. However, as the number of intermediate supports is increased the number of variable parameters such as the various intervals, stiffnesses and eccentricities, multiply rapidly and the general theory becomes more and more involved. Therefore, it appeared useful to develop an apparatus with which the more complicated problems could be readily solved by measurements in model scale, provided the technique was first tested on cases for which a theoretical solution was available.

Such an apparatus was built at the Goodyear-Zeppelin Corporation. (See Fig. 1). This machine is an outgrowth of an earlier apparatus made by L. H. Donnell [3] at the California Institute of Technology to demonstrate the transition between multiple wave types of failure of compressed columns when the stiffness of

[1] M. Schwartz and R. Bogert, *Analysis of a Strut with a Single Elastic Support in the Span, etc.*, N. A. C. A. Technical Note No. 529, Washington, D. C., 1935.

[2] S. Timoshenko, *Theory of Elastic Stability*, Engineering Societies Monograph, 1936.

[3] Aeronautical Engineering Transactions of the A. S. M. E., Vol. 5, No. 4, October-December 1933.

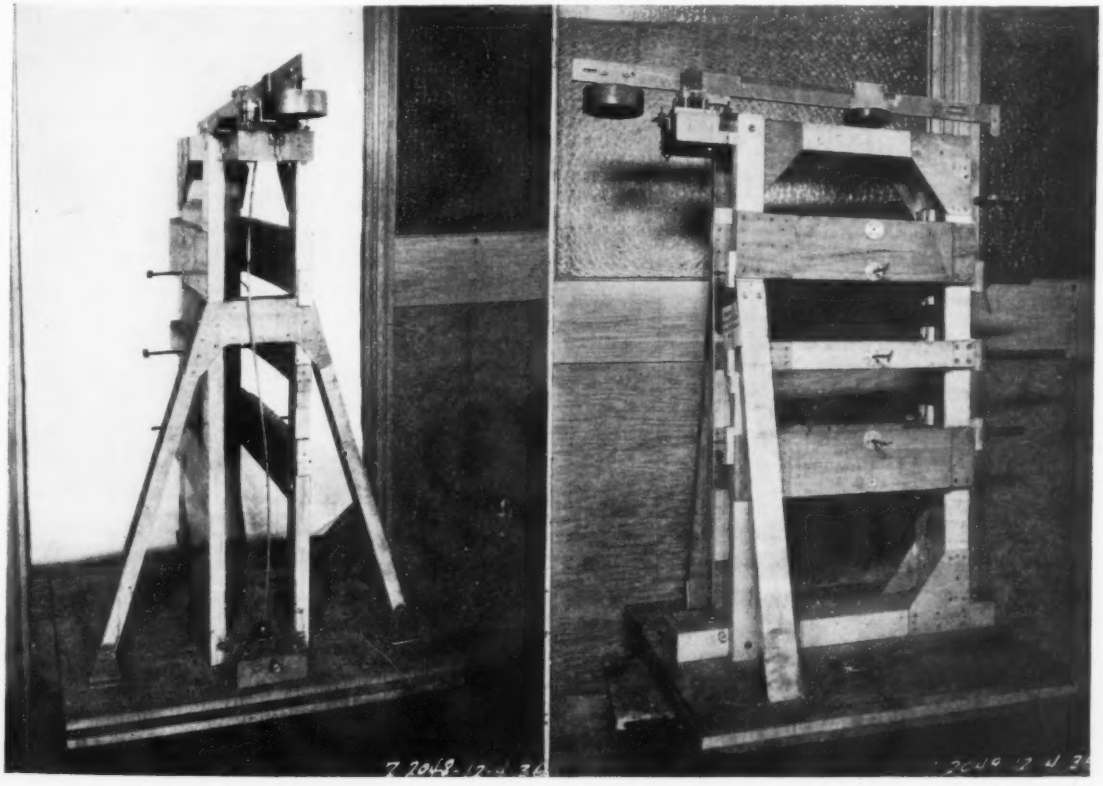

FIG. 1.

a great number of equally spaced supports is increased. (See references 2, 4 and 5).

The present machine has the additional features of a weighing beam on which the load can be measured and of lateral displacement of the neutral position of the supports. The weighing beam rests on a double acting knife-edge yoke supported on a strong wooden frame. The model column is a $\frac{3}{16}$" duralumin drawn rod 36" long having a slenderness ratio of 770. The ends of the rod are set in conical pointed tips resting in conical cups. These terminal tips allow almost unrestrained freedom of inclination. The great slenderness ratio permits of large elastic deflection without danger of exceeding the yield limit of the material. Provision was made for one, two or three intermediate supports. Each intermediate support is represented by a cantilever beam of hardened drill rod connected to the column by small eyelet clips. The back end of each cantilever spring rod is rigidly clamped in a stiff steel sleeve which can be telescoped in or out so as to vary the free cantilever length of the support spring and thus its effective stiffness. The effective stiffness was calibrated by means of a weight and pulley. Initial lateral displacement could be produced by a thumbscrew controlled lateral swivel arrangement of the anchorage of the sleeves. Deflections were large enough to be measured by sighting over a scale to $\pm.005$". Various diameters of rod were employed for the supports in order to cover the desired ranges of stiffness with the length of cantilever varying from about 6" to 12".

This machine was used, first, to develop a technique of sufficient accuracy to check the available theoretical results for some typical cases and then to explore a field of more complex nature. The experiments to be reported here cover the cases of two and three equal bays.

The Euler load $Q=\pi^2EI/L^2$ of the unsupported straight column of length $L=36$" was found to be 4.8 $\pm.1$ lbs. This would correspond to an Elastic Modulus of $E=10{,}500{,}000$ lbs./in.,[2] which is reasonable. The technique developed for the determination of the critical load consisted in manually assisting the column and gradually withdrawing the manual support from it while in neutral position.

Fig. 2 shows the results of the measurements of the initially straight (within .02") column with one and two supports. The results are plotted in non-dimensional terms as "reinforcement" (p) versus relative stiffness (s). The reinforcement is defined as the ratio of actual buckling load P to Euler load Q of the unsupported column, *viz.* $p=P/Q$. The relative stiffness is defined as $s=SL/Q$ where S is the spring constant of the elastic support.

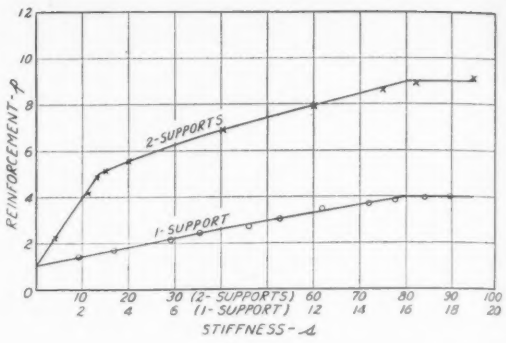

FIG. 2.

The solid lines in Fig. 2 are the plot of the theoretical correlations between p and s. The experimental points fit the theoretical curves so well that the experiments may serve to verify the accuracy and technique of experimentation. This was the more appreciated since the difficulties of obtaining consistent results in experiments involving unstability are well known. At $s=13.3$, where the break in the curve for two supports occurs, the transition from symmetrical (half wave) flexure to anti-symmetrical (full wave) flexure was clearly observed in the experiment.

The following figures give the results of experiments with initially cambered columns, *i.e.* columns which under no axial loads were held by the intermediate supports in a bowed shape. Within the realm of elastic deformations the bowing increases under load independently of whether an originally straight column was bent by attaching laterally displaced elastic supports or whether a similar camber was built into the column and the elastic supports. In general, the application of axial load will increase the initial flexure of the column and cause it hyperbolically to grow out of bounds when the critical load of the equivalent straight column is approached. There are exceptions to this rule, however, for example when the initial eccentricities at support stations are to opposite sides while the type of critical failure governed by the support stiffness would be of the symmetrical type or vice versa. This phenomenon was explained by Timoshenko (see reference 2). It was clearly demonstrated in the present tests.

For the experiments with initially cambered columns, the progressive deflection at a support station with increasing load has been plotted on the following figures, again in a non-dimensional system. The ordinates represent the loads in terms of $p=P/Q$ and the abscissae the relative increase of deflection $\eta=y/y_0$ where y is the actual displacement of the supported point from the column axis under load and y_0 was the same under no axial load. For the cases where the theoretical correlation between η and p was computed

[4] W. B. Klemperer and H. B. Gibbons, *On the Buckling Strength of Beams Under Axial Compression Bridging Elastic Intermediate Supports*, A. S. M. E. National Applied Mechanics Meeting, New Haven, June 1932.

[5] See other literature quoted in references 2 and 4.

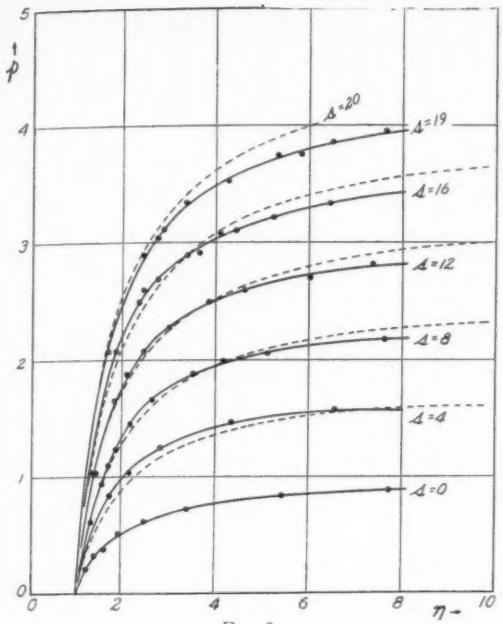

FIG. 3.

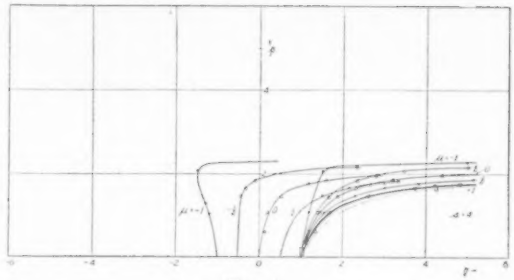

FIG. 4.

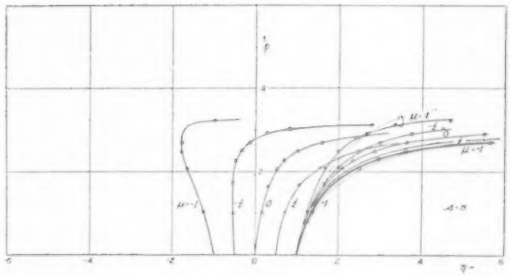

FIG. 5.

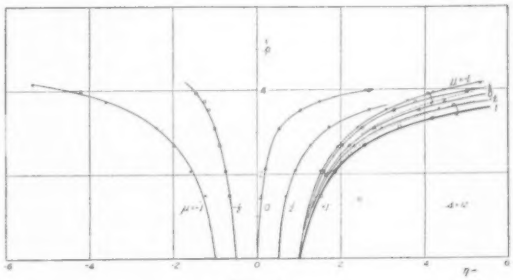

FIG. 6.

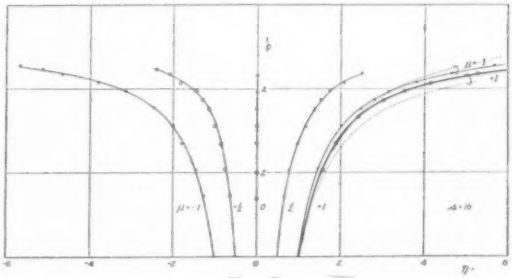

FIG. 7.

by an approximation, the calculated curves are shown as dashed lines. Only where the deflections become very large and second order terms may not have been negligible, is there an appreciable departure of experimental results from the approximate theory. In cases of symmetry the deflection y at the support station varies but little from $y_0P_c/(P_c—P)$, where P_c is the critical load.

The experimental technique seemed to be satisfactory and applicable to more complicated cases.

Fig. 3 gives the results for a single midspan support. With two supports five different conditions of initial camber were investigated. Taking one support as the datum point, the ratio of the eccentricity of the other support to the reference support has been designated as μ. The ratios chosen were $\mu=+1,+½,0,—½$ and $—1$, covering the range from symmetrical to anti-symmetrical camber, the latter being indicated by $\mu=—1$. These ratios are marked on the respective graphs as parameters. The heavy lines for $\mu=+1$, indicate two coincident curves, since for this condition symmetrical flexure can be maintained up to relatively large values of s. For convenience the reference support has been designated as No. 1 support and the other as No. 2 support. Initial deflection at No. 1 was chosen as .25″.

Figs. 4 to 9 refer to experiments with two equally stiff supports but for various initial displacement at the support stations. Figs. 4 and 5 show that for low values of stiffness, *viz.* $s=4$ and 8 respectively, symmetrical flexure ultimately prevails even for wholly anti-symmetrical initial camber. For the condition $\mu=—1$, a markedly indifferent behavior was noted in the transition from anti-symmetrical to symmetrical flexure. For $s=12$ shown on Fig. 6, which is close to the value $s=13.3$ at which transition from symmetrical to anti-symmetrical flexure occurs with the straight column, ultimate flexure is symmetrical between $\mu=+1$ and about $\mu=—¼$, and becomes anti-symmetrical as μ becomes increasingly negative. For $s=16$ shown on Fig. 7 which is a little above the straight column critical value of 13.3, the transition is definitely placed at $\mu=0$ as indicated by the complete absence of

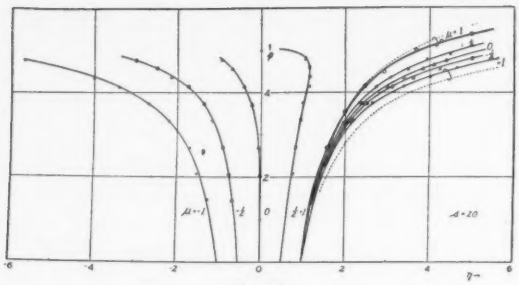

FIG. 8.

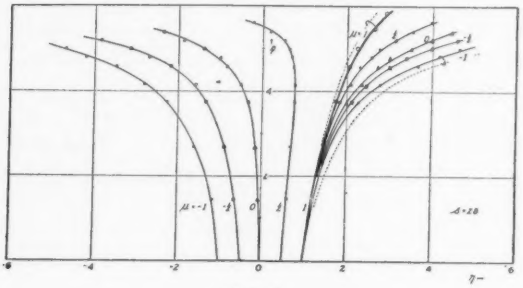

FIG. 9.

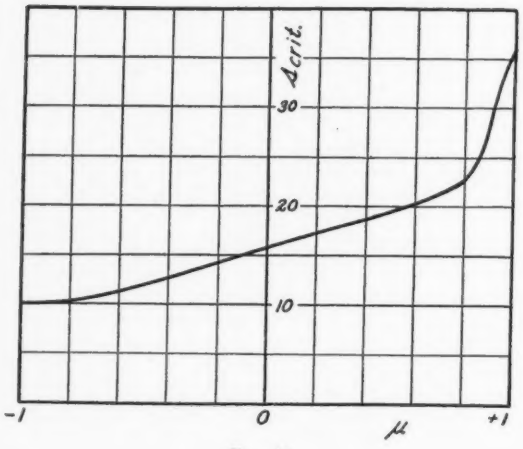

FIG. 10.

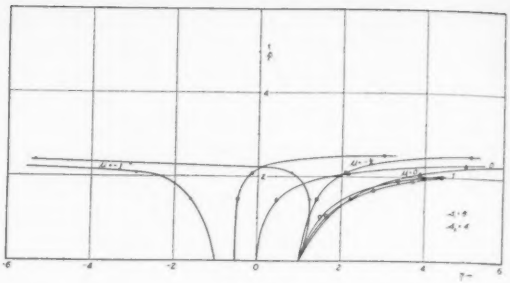

FIG. 11.

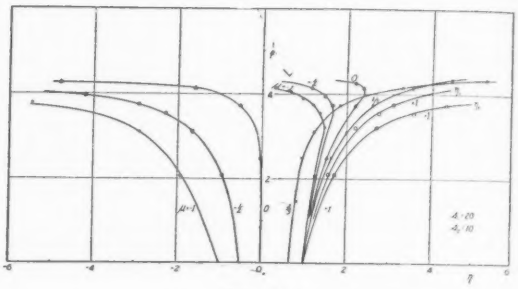

FIG. 12.

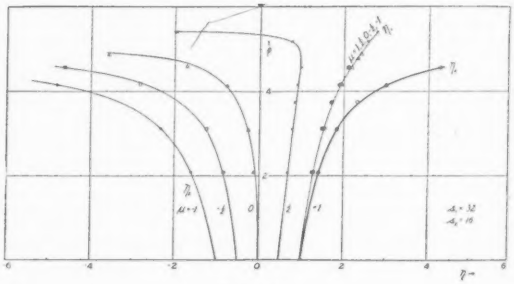

FIG. 13.

deflection at No. 2 support. With increase of stiffness up to $s=20$ and $s=28$, shown on Figs. 8 and 9 respectively, the tendency naturally swings the other way and anti-symmetrical flexure prevails except for $\mu=+1$. For $s=28$ the transition from symmetrical to anti-symmetrical flexure occurs up to $\mu = + .88$, though the former can still be maintained for $\mu=+1$.

It is noteworthy that for small stiffness, the reinforcement p increases as μ changes from $+1$ toward -1, while for larger stiffnesses above the critical of $s=13.3$, p decreases with change of μ from $+1$ to -1. This is reasonable inasmuch as for small stiffnesses symmetrical camber enhances and anti-symmetrical camber counteracts the tendency toward symmetrical flexure under increasing load, whereas for large stiffness symmetrical camber counteracts and anti-symmetrical camber enhances the tendency toward anti-symmetrical flexure. A few experiments at higher values of s served to establish that the limit for symmetrical ultimate flexure occurs at about $s=36$.

From these data one can roughly interpolate a critical stiffness for varying values of μ in the sense that for greater stiffness anti-symmetrical flexure will prevail, while for lesser stiffness symmetrical flexure will prevail regardless of the shape of the initial camber of the column. The variation of this critical stiffness with μ is approximately shown on Fig. 10.

Figs. 11 to 13 show the effect of unequal stiffness between the two supports. In these figures the stiffness of No. 2 support was one-half the stiffness of No. 1 support, for values of the latter of $s=8$, 20, and 32 respectively. The flexure tends to be in the direction of the eccentricity of the weaker support when μ is sufficiently small or increasingly negative to make its influence felt.

Summary

The behavior of initially cambered and S shaped columns with elastic intermediate supports of different stiffness and eccentricity can quickly be determined by an experimental method employing model columns and wire spring supports.

Appendix

Theoretical relations between the support stiffness and the reinforcement obtained for straight columns with one or two regularly spaced supports are:

One support in mid-span; straight column:

$$s_1 = 4\,p\,\phi/[\,\phi - 2\tan\phi/2]$$

where $\phi = \pi\sqrt{p}$

Two supports (three bays); straight column:

symmetrical flexure impending:

$$s_2 = 3p\phi/[\phi - 3(\sin^2\phi/3 \cdot \tan\phi/2 + \sin\phi/3 \cdot \cos\phi/3)]$$

anti-symmetrical flexure impending:

$$s_3 = 9\,p\phi/\,[\phi - 9/(\cot\phi/3 + \cot\phi/6)]$$

An approximate relation for the progressive increase of an initial displacement at midspan, with one support of stiffness s is

$$\eta_1 = (s + 48/\pi^2)/(s - s_1)$$

For two supports of equal stiffness $s < 13.3$, at $\frac{1}{3}$ and $\frac{2}{3}L$, with symmetrical initial displacement at both support stations, the corresponding relation is

$$\eta_2 = (s + 162/5\pi^2)/(s - s_2)$$

For two such supports of equal stiffness, $13.3 < s < 81$, at $\frac{1}{3}$ and $\frac{2}{3}L$, with anti-symmetrical (S shaped) initial displacements at support stations, it is

$$\eta_3 = (s + 486/\pi^2)/(s - s_3)$$

The increase of camber is here expressed in terms of actual support stiffness s and that stiffness (s_1, s_2 or s_3) which would be required for the straight column under the same load. The numerical constants appearing in the above equations with π^2 in the denominator entered as the effect of the bending moments that would accompany an initial deflection under a concentrated lateral force without axial load. These coefficients are approximate, inasmuch as the cubic parabola sag curve differs slightly from a segment of a sine wave. However, the influence of this approximation is negligible, as can be ascertained by comparison with the solution in terms of a Fourier series approximation of the initial deflection curve as given in reference *2*.

Letter to the Editor

January 19, 1937

Dear Sir:

Mr. Metcalf's paper, which appeared in the December 1936 issue of the Journal (page 61), gave an authoritative and concise résumé of the theoretical treatment of the longitudinal stability of airplanes. My own reasoning on this subject, however, leads me to make strong objections to the interpretation of the dynamical theory as outlined in Mr. Metcalf's paper and as employed by many investigators in the past.

Mr. Metcalf states that a certain mode, namely the "short period" oscillation, which appears in the calculated motion of the airplane, is of negligible importance in considerations of longitudinal stability and control. It is true that mathematical investigators in the past, seeking to uncover the possibility of an innate instability of the airplane, have refused consideration of this mode of the motion since it invariably showed great damping. Such damping means that, in calm air, the motion will subside quickly, but it also means that there is an effective restraint of the machine against movements relative to the air which will result in violent movements of the airplane in gusts. Rolling is the most heavily damped component of the airplane's motion and it is for this reason that banks occur with such disconcerting suddenness in rough air, and also that the most powerful of the three controls is required to cause movement about this axis.

If we are to confine ourselves to the academical problem of predicting the ultimate disaster to a pilotless airplane flying in calm air, it will be proper to neglect the heavily damped oscillation. If, however, we wish to make more practical use of the dynamical theory so as to analyze and predict the response to control and the motions in gusty air, we cannot neglect this factor which is of primary significance in these questions.

It is frequently held desirable to make the period of the phugoid motion as slow as possible in terms of the reaction time of the pilot. It appears, however, that the frequency of this type of oscillation cannot exceed a certain rate and that rate is so moderate that its existence is masked by the small disturbances and corrections that are continually occurring. The shortest period of the phugoid motion is given by Lanchester's formula, namely

$$T = \sqrt{2}\,\pi\frac{v}{g},$$

or about 40 seconds at 200 miles per hour. Actual airplanes show periods longer than given by this formula and a damping or divergence of the oscillations is, if present, small. As pointed out by Mr. Metcalf, the most effective damping of this mode is that due to the drag of the airplane. The oscillation depends mainly on the forward velocity and on gravity.

Recent experiments made by the N.A.C.A. (Technical Report No. 578) led to the conclusion that trained test pilots could detect no correlation between the measured phugoid characteristics of a number of different airplanes and their apparent handling qualities.

In the light of the conclusion reached in Technical Report No. 578, it is apparent that we must exert a greater effort to bring the practical aspects of the dynamics of flight to a rational basis. More students and investigators of this subject are needed and the subject needs to be popularized for students, perhaps as Steinmetz popularized the dynamics of electricity. Discussions in the Journal, such as Mr. Metcalf's should help toward this end.

Robert T. Jones

National Advisory Committee for Aeronautics

Formulae for Altimeter Corrections

PHILIP DALTON, *Washington, D. C.*

(Received October 19, 1936)

ALTIMETERS in use in the United States are calibrated for the U. S. Standard Atmosphere, in which; the sea-level pressure is 29.92 inches of mercury, the sea-level temperature is +15°C., and the temperature lapse rate up to 35,332 feet is 1.9812°C. per thousand feet of altitude.[1] Under these hypothetical conditions a standard altimeter set to read zero at sea level would read true altitudes above sea level. Also, altimeters are constructed with linkages and uniformly graduated scales arranged so that, when the scale or mechanism is rotated to set the pointer at zero for any desired pressure level, the instrument will read true altitudes above that pressure level in the standard atmosphere.

When an altimeter is set to read zero at the standard sea-level pressure, its readings are called "pressure altitude" or sometimes "29.92 altitude." When it is set to read zero at any other pressure level, such as a certain ground level, its readings are called "indicated altitude." Due to the manner in which altimeters are constructed with uniform scales and "zero setting devices," an indicated altitude above the ground is the difference between the pressure altitudes at the flight level and the ground level.

The standard atmosphere is a fairly close approximation of average atmospheric conditions thruout the year in the United States. But the fluctuations between summer and winter temperatures are often great, as are the differences between tropical and arctic temperatures. With the lapse rate and sea-level pressure remaining standard, a shift of the sea-level air temperature of 10°C. from the standard sea-level air temperature of +15°C. will cause an altimeter error of roughly 3½%. Likewise, a variation of sea-level barometric pressure of one-tenth of an inch of mercury from standard sea-level pressure will cause an error in indicated altitudes of roughly 0.07%.

The exact correction of these errors requires a record of the air temperatures at regular intervals of pressure altitude thruout the air column. However, if it is assumed that the standard temperature lapse rate exists, an indicated altitude can be corrected simply from the air temperature and pressure altitude at the flight level. Or if the air temperature and pressure altitude at both the flight level and the ground level are known, a better correction generally can be obtained by assuming that the temperature lapse rate is uniform but not necessarily standard. The derivation of formulae for these corrections, and a description of a computer for applying them, is given below.

The general formula for the relation between pressures, temperatures, and altitudes in the atmosphere[2] may be expressed as:

$$\frac{R}{g}\log\frac{P_1}{P_0}=\frac{1}{K}\log\left(1-\frac{KH}{T_0}\right) \qquad (1)$$

in which,

R = the gas constant,
g = the acceleration of gravity,
P_1 = the pressure at an upper level,
P_0 = the pressure at a lower level,
K = the temperature lapse rate,
T_0 = the temperature (absolute) at the lower level,
H = the altitude between the upper and lower levels.

Since altimeters are constructed to read true altitudes in the standard atmosphere, the relation between pressures and altimeter readings can be obtained by substituting the constants of the standard atmosphere in the general Eq. (1) as follows. Let:

$K = K_s$, the standard temperature lapse rate,
$H = Z$ or $(Z_1 - Z_0)$, the indicated altitude or the difference between the pressure altitudes Z_1 and Z_0 at the pressure levels P_1 and P_0,
$T_0 = 288 - K_s Z_0$, the absolute temperature at the lower level.

Then the general Eq. (1) becomes the altimeter formula,

$$\frac{R}{g}\log\frac{P_1}{P_0}=\frac{1}{K_s}\log\left(1-\frac{K_sZ}{288-K_sZ_0}\right) \qquad (2)$$

If it is assumed that the standard temperature lapse rate exists in the actual atmosphere, and K_s is substituted for K in the general Eq. (1), the formula for the atmosphere becomes,

$$\frac{R}{g}\log\frac{P_1}{P_0}=\frac{1}{K_s}\log\left(1-\frac{K_sH}{T_0}\right) \qquad (3)$$

Since Eqs. (2) and (3) are independent of the particular values of P_1 and P_0, P_1 and P_0 may be left respectively identical in the two equations and the

[1] W. G. Brombacher, *Altitude-Pressure Tables Based on the United States Standard Atmosphere*, N.A.C.A. Report No. 538, Washington, D. C., 1935.

[2] C. J. Stewart, *Aircraft Instruments*, pages 2-5, 1930.

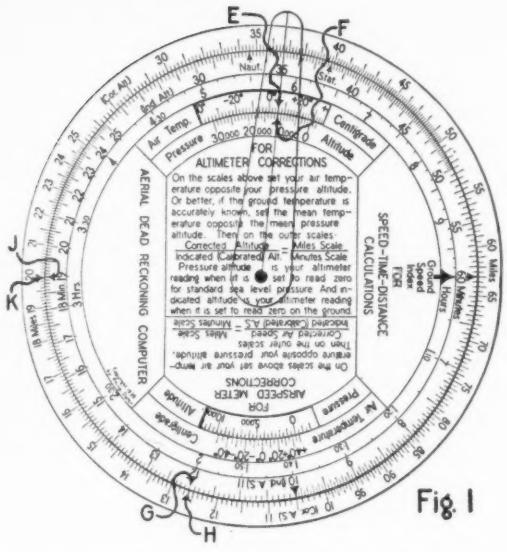

Fig. 1

right-hand terms of the equations may be equated to find the relation between H and Z in terms of temperatures,

$$\frac{Z}{288 - K_s Z_0} = \frac{H}{T_0} \tag{4}$$

Substituting:

$Z = Z_1 - Z_0$, and

$T_0 = T_1 + K_s H$, in which T_1 is the air temperature (absolute) at the flight level,

$$\frac{H}{Z} = \frac{T_1}{288 - K_s Z_1} \tag{5}$$

This means, that if it is assumed that the standard lapse rate exists in the actual atmosphere, the altimeter correction factor H/Z is the ratio of the actual flight-level air temperature to the standard air temperature for the flight-level pressure altitude.

It is interesting to note that this correction factor, as taken directly from Eq. (4),

$$\frac{H}{Z} = \frac{T_0}{288 - K_s Z_0}$$

is also the ratio of the actual ground-level air temperature to the standard air temperature for the ground-level pressure altitude. But since the air temperature and pressure altitude at the flight level are available to the aviator without any computations, Eq. (5) is preferable.

Means for applying this correction factor to indicated altitudes have been incorporated in a navigational computer, as shown in Fig. 1. The computer is a continuous scale circular slide rule with scales equivalent to the C and D scales of an ordinary Mannheim slide rule. As these scales are primarily used for speed—time—distance computations they are labeled "Miles" and "Minutes." As shown at E and F in Fig. 1, additional scales labeled "Air Temp., Centigrade" and "Pressure Altitude" are provided for altimeter corrections.

The air temperature scale is logarithmically divided according to the absolute temperatures equivalent to the centigrade temperatures with which it is labeled. The pressure altitude scale is logarithmically divided according to the absolute temperatures in the standard atmosphere equivalent to the pressure altitudes with which it is labeled. The logarithmic divisions of both correction scales are on the same basis as those of the outer "Miles" and "Minutes" scales, i.e., $log_{10} 10 = 2\pi r$. And the correction scales are oriented so that, when the outer scales are numerically coincident, altitudes on the pressure altitude scale fall opposite the equivalent temperatures in the standard atmosphere. Thus, if the actual temperature and pressure altitude at the flight level vary from those of the standard atmosphere, setting their actual values opposite each other on the correction scales, as shown at E and F in Fig. 1, will set up on the outer scales the ratio of the absolute flight-level air temperature to the absolute standard air temperature for the flight-level pressure altitude, according to Eq. (5). The corrected altitude H is read from the "Miles" scale opposite the indicated altitude Z on the "Minutes" scale, as at G and H in Fig. 1.

When the air temperatures and pressure altitudes are known at both the flight level and the ground level, it is not necessary to assume that the standard lapse rate exists. Assuming, however, that the lapse rate is uniform thruout the air column, the best correction can be made as follows:

Substituting $288 - K_s Z_0 = T_{0s}$, in which T_{0s} is the standard air temperature equivalent to the ground-level pressure altitude, the altimeter Eq. (2) becomes

$$\frac{R}{g} \log \frac{P_1}{P_0} = \frac{1}{K_s} \log \left(1 - \frac{K_s Z}{T_{0s}}\right) \tag{6}$$

Equating the right-hand terms of the general Eq. (1) and the altimeter Eq. (6),

$$\frac{1}{K} \log \left(1 - \frac{KH}{T_0}\right) = \frac{1}{K_s} \log \left(1 - \frac{K_s Z}{T_{0s}}\right) \tag{7}$$

In Eq. (7) the quantities $log\left(1 - \frac{KH}{T_0}\right)$ and $log\left(1 - \frac{K_s Z}{T_{0s}}\right)$ can be expanded into infinite series of the form,

$$\log x = 2\left[\left(\frac{x-1}{x+1}\right) + \frac{1}{3}\left(\frac{x-1}{x+1}\right)^3 + \frac{1}{5}\left(\frac{x-1}{x+1}\right)^5 + \ldots\right]$$

in which KH and $K_s Z$ are so small as compared to $2T_0$ and $2T_{0s}$ respectively, that all but the first terms of the series can be neglected, giving

$$\frac{H}{2T_0 - KH} = \frac{Z}{2T_{0s} - K_s Z}$$

Substituting $KH=T_0-T_1$, $Z=Z_1Z_0$, and $T_{0s}=288-K_sZ_0$, gives

$$\frac{H}{Z}=\frac{\frac{1}{2}(T_1+T_0)}{288-K_s\frac{1}{2}(Z_1+Z_0)} \tag{8}$$

This means that, assuming a uniform but not necessarily standard lapse rate between the ground and flight levels, the correction factor H/Z is the ratio of the existing mean air temperature (absolute) to the standard air temperature (absolute) equivalent to the mean of the pressure altitudes at the ground and flight levels. This correction factor is applied on the computer described above by setting the mean air temperature opposite the mean pressure altitude on the correction scales, as shown at E and F in Fig. 1, and reading the corrected altitude from the "Miles" scale opposite the indicated altitude on the "Minutes" scale, as shown at J and K in Fig. 1.

The only approximation in the derivation of Eq. (8) is that involved in neglecting all but the first terms in the logarithmic expansion used. It can be shown that the errors of the formula due to this approximation are as follows.

Case 1. When standard atmospheric conditions exist the error of the formula is zero.

Case 2. Let atmospheric conditions be standard except for a sea-level pressure altitude of —2,000 feet instead of zero, for example, let

Z = 10,000 ft. T_0 = + 15°C.
Z_0 = −2,000 ft. T_1 = −5°C.
Z_1 = +8,000 ft.

Then the correction to the indicated altitude according to Eq. (8) and the error of the equation are,

Altitude correction=1.4%, Formula error=0.002%.

Case 3. Let conditions be standard except for an extreme shift of the temperature distribution;

Z_0 = 0 T_0 = +50°C. (122°F.)
Z_1 = 10,000 ft. T_1 = +30°C.

Then,

Altitude correction=12.5%, Formula error=0.008%.

Case 4. Let conditions be standard except for a zero lapse rate;

Z_0 = 0 T_0 = +15°C.
Z_1 = 10,000 ft. T_1 = +15°C.

Then,

Altitude correction=3.6%, Formula error=0.04%.

Case 5. Let conditions be the most extreme that are apt to occur in practice;

Z = 20,000 ft. T_0 = −35°C. (−31°F.)
Z_0 = −2,000 ft. T_1 = −55°C.
Z_1 = 18,000 ft.

Then,

Altitude correction =16.2%, Formula error=0.11%. Thus it can be seen that the approximation involved in the derivation of Eq. (8) introduces an error which is quite negligible.

Of course, in the use of these formulae, the error due to the assumption that either the standard or a uniform lapse rate exists can not be avoided. However, great irregularities in the lapse rate are the exception rather than the rule. And even in the case of a temperature inversion, if the temperature distribution is considerably above or below the standard distribution, the assumption of the standard or a uniform lapse rate will permit a useful correction.

The author wishes to thank Dr. W. G. Brombacher of the Bureau of Standards and Dr. Arnold M. Kuethe of the Daniel Guggenheim Airship Institute for their helpful criticisms and suggestions.

Book Reviews

Once to Every Pilot, by CAPT. FRANK HAWKS; Stackpole Sons, New York, 1936; 144 pages, ill., $1.50.

Frank Hawks is generally regarded as the most articulate of all the famous pilots and the book of yarns which he has collected substantiates this impression.

He has listened to many thrilling stories of hazardous flying and selected a few which make excellent reading. Eddie Allen, Jimmie Mattern, Wiley Post, Eddie Rickenbacker, Al Williams, as well as the author tell of the most exciting adventure they have had in their flying experiences, hence the title of the book. Whether or not such tales give the public too vivid an impression of the dangers of flying is a question open to argument. The fact that all survived may counteract any idea a reader may get that flying is a series of dangerous experiences. No one could have selected the experiences with a more discriminating background. Frank Hawks knows whether or not a pilot enlarged on facts with his imagination or was in real trouble. Therefore, these stories may be considered authentic accounts of genuine predicaments encountered by some of the most experienced pilots in the world.

From Heston to the High Alps, by DOUGLAS FAWCETT; Macmillan & Co., Ltd., London, 1936; 74 pages, ill., 6s.

When a gentleman 68 years old learns to fly it is natural that his impressions and reactions are somewhat different from those of younger student flyers. Mr. Fawcett has written of his experiences in prose and verse with the skill of an experienced author. He takes his reader through his course at Hendon and then demonstrates his ability by describing several flights over the unequalled scenic beauty of the Alps. The book was written to encourage amateurs who wish to become private owners of aircraft. It succeeds in making the first steps in flying instruction so simple that the book should do much to encourage others to fly. Its main purpose is to give young men and women an account of the first stages in the art of flying; stages mastered by one who, by virtue of his age, might be held barely qualified for his task. The illustrations of views of the Alps are in themselves an alluring inducement to anyone to wish to become a pilot.

A Method of Fairing Control Surfaces

FRED N. DICKERMAN, *Chance Vought Aircraft*

(Received November 16, 1936)

WITH full cantilever tail surfaces, using a conventional symmetrical airfoil section, some trouble had been experienced in the form of "dead spots" in the action of the movable tail surface. Small displacements of the movable surface from its normal position did not produce the desired corresponding movement on the part of the airplane. Experience proved that this difficulty could be overcome by using an airfoil section with a straight line camber from the hinge line to the trailing edge, this straight line being tangent to the camber forward of the hinge line. Such an airfoil section is shown in Fig. 1, together with a conventional type of tail airfoil.

Since a new section had to be developed to fulfill this condition, it was desirable to incorporate certain other advantages in the section. It should have a simple mathematical formula in order that a section of any given thickness ratio and chord length could be derived easily. Secondly, the slope of the section at any point, as expressed by the first derivative of the camber, should also be a simple mathematical formula to facilitate fairing between the end ribs of any tail surface in order to make the skin a developable surface.

The formula finally chosen for the forward or curved portion of the airfoil was:

$$y = A\sqrt{x} - Bx^2 \tag{1}$$

where y=semi-camber in % of chord

x=distance from leading edge in % of chord

The slope of this curve at any point is, of course:

$$\frac{dy}{dx} = \frac{A}{2\sqrt{x}} - 2Bx \tag{2}$$

The method of developing a particular section and of evaluating the constants A and B is as follows: See Fig. 1.

It is assumed that x_0 is known from the plan form of the tail surface in question. First choose a value for y_0. This will depend upon the depth desired for the rear beam of the fixed surface (if it is of the two-spar type) and the beam of the movable surface. Determine the value of $y_{T.E.}$ which will depend upon the trailing edge construction in use. Then if the slope of the straight rear part of the section be called $-S$

$$-S = \frac{-(y_0 - y_{T.E.})}{100 - x_0} \tag{3}$$

By substituting all the now known values in Eqs. (1)

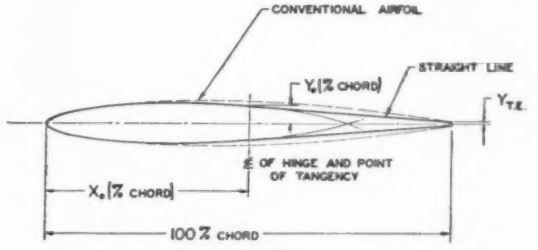

FIG. 1.

and (2) the following simultaneous equations result.

$$y_0 = A\sqrt{x_0} - Bx_0^2 \tag{4}$$

$$-S = \frac{A}{2\sqrt{x_0}} - 2Bx_0 \tag{5}$$

Solving these equations gives

$$A = \frac{4y_0 + 2Sx_0}{3\sqrt{x_0}} \tag{6}$$

$$B = \frac{y_0 + 2Sx_0}{3x_0^2} \tag{7}$$

Since x_0, y_0, and S are already known, numerical values for A and B are easily found.

The next step is to make a tabulation similar to Table 1. The first three columns of this table will be the same for any section, if the usual stations along the chord are used. The table should be filled in for values of x as far aft as the hinge line.

It is usually necessary to know the maximum thickness of the section and its location from the leading edge. This may be found by letting $dy/dx=0$ in Eq. (2) and finding the corresponding values for x and y. It is well to do this immediately after determining A and B, before working out all the ordinates of the section. If the maximum thickness is too great or too small it can be altered by changing the value of y_0 slightly.

The leading edge radius of the section is derivable from the formula for radius of curvature.

$$R = \frac{\left[1 + \left(\frac{dy}{dx}\right)^2\right]^{\frac{3}{2}}}{\frac{d^2y}{dx^2}}$$

$$\frac{dy}{dx} = \frac{A}{2}x^{-\frac{1}{2}} - 2Bx$$

$$\frac{d^2y}{dx^2} = -\frac{A}{4}x^{-\frac{3}{2}} - 2B$$

TABLE 1

1	2	3	4	5	6	7	8	9	10
x % Chord	$\sqrt{x}$	x^2	$A\sqrt{x}$	Bx^2	y % CHORD = (4) − (5)	y Inches = y (%) x CHORD	$\frac{A/2}{\sqrt{x}}$	(2B)x	$\frac{dy}{dx}$ = (8) − (9)
.625	.790	.391							
1.25	1.118	1.562							
2.50	1.581	6.25							
5.00	2.236	25.00							
7.50	2.739	56.25							
10.00	3.162	100.							
15.00	3.873	225.							
20.00	4.472	400.							
25.00	5.000	625.							
30.00	5.477	900.							
40.00	6.324	1600.							
50.00	7.071	2500.							
60.00	7.746	3600.							
70.00	8.367	4900.							
80.00	8.944	6400.							
90.00	9.487	8100.							

$$R = \frac{\left[1 + \left(\frac{A}{2}x^{-\frac{1}{2}} - 2Bx\right)^2\right]^{\frac{3}{2}}}{-\frac{A}{4}x^{-\frac{3}{2}} - 2B}$$

$$= \frac{\left[1 + \frac{A^2}{4}x^{-1} - 2ABx^{\frac{1}{2}} + 4B^2x^2\right]^{\frac{3}{2}}}{\frac{-A - 8Bx^{\frac{3}{2}}}{4x^{\frac{3}{2}}}}$$

$$= \frac{[4x + A^2 - 8ABx^{\frac{3}{2}} - 16B^2x^3]^{\frac{3}{2}}}{(4x)^{\frac{3}{2}}} \cdot \frac{4x^{\frac{3}{2}}}{-A - 8Bx^{\frac{3}{2}}}$$

$$= \frac{[4x + A^2 - 8ABx^{\frac{3}{2}} - 16B^2x^3]^{\frac{3}{2}}}{2} \cdot \frac{1}{-A - 8Bx^{\frac{3}{2}}}$$

When $x = 0$ $R = \frac{[0 + A^2 - 0 - 0]^{\frac{3}{2}}}{-2A}$

$$= -\frac{A^3}{2A}$$

$$R = -\frac{A^2}{2}$$

Having determined the root and tip sections of the fixed portion of a tail surface by the above method, the intervening ribs should be made so that the skin will be a developable surface. If this is done the skin can be wrapped on the ribs without any buckling or forming. The theory of developable surfaces and a graphical method of constructing them was well explained by Antony Thivat in an article entitled *The Covering of Curved Surfaces* ("Airway Age," Vol. II, No. 9.)

Briefly the method consists in drawing straight lines or generatrices between points on the two end sections which have the same slope. However, in the case of tail surface sections, which are relatively flat, it is very difficult to determine graphically points having the same slope.

To overcome this objection, the slope equation for this airfoil was made as simple as possible, as mentioned earlier in this article. This made possible the following method of fairing between the root and tip sections.

Plot the slope of each of the two sections on the same sheet of graph paper, using per cent of chord from the leading edge as the abscissa. (See Fig. 2). From any point on the slope curve of the root section draw a horizontal line *"A–A"* to intersect the slope curve of the tip section. This intersection locates the point on the tip section which has the same slope as the point chosen on the root section.

The line *A–A* is a generatrix of the desired surface and should be located on a layout similar to Fig. 3. Project the intersections of line *A–A* and the intermediate ribs in the plan view to the end view, thus deter-

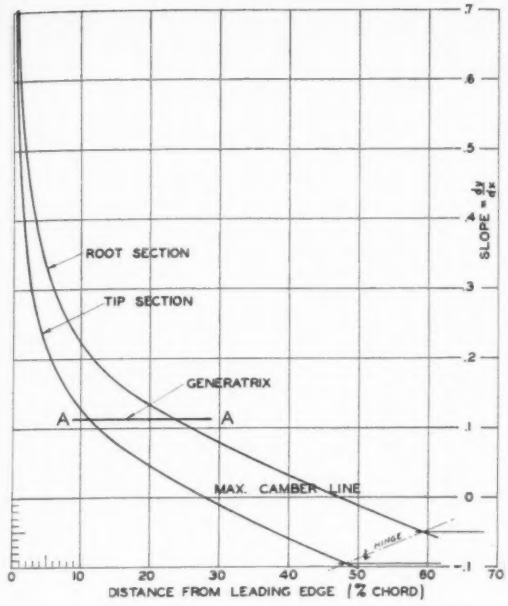

FIG. 2. Slope *vs.* distance from leading edge plotted for root and tip sections to determine generatrices of surface.

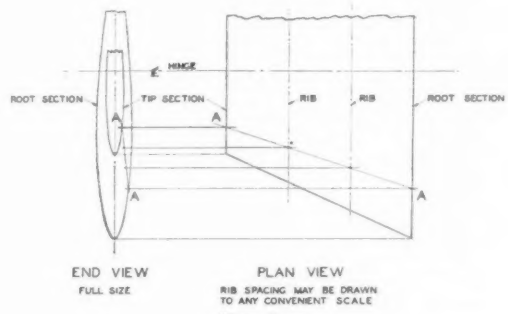

FIG. 3.

mining points on the intermediate rib contours. In this layout the end view may well be made on a piece of sheet metal painted white, to serve as a master template of the rib sections. The plan view may be on paper as it will not be needed once the sections are determined. Of course it is obvious that if all the intermediate ribs are equally spaced, a plan view will not be necessary at all. The line *A–A* in the end view can be divided into the proper number of equal parts. Furthermore, even if the ribs are not equally spaced the line *A–A* could be divided mathematically into parts proportional to the spacing and the plan view eliminated. However, experience has shown definitely that the graphical method is quicker and equally satisfactory in this latter case.

FIG. 4.

By taking a suitable number of lines similar to *A–A*, any number of points on the rib contours may be found. A convenient way is to draw one from each of the station points used in plotting the root section.

Naturally beams and skin stiffeners should be along generatrices or lines similar to *A–A* in the plan view wherever possible in order that their flanges may be straight rather than curved. For this reason it is advantageous to make the slope at the hinge line the same for both root and tip sections, but this is not necessary. The sections are generally so flat near the hinge line that the rear beam of the fixed surface can be made a straight taper regardless of whether it lies along a generatrix. In this event, the intervening sections are to be modified slightly to meet the beam. The amount of error involved should be checked in any case.

Using this method, and given the plan form, rib locations, hinge line location and thickness ratios required at the root and tip, the designer can quickly develop all the sections required for a tail surface which will be remarkably free from "dead spots" aerodynamically, and will provide a developable surface on which the skin can be wrapped. Fig. 4 shows a typical tail group which was designed by this method. The intersection between the horizontal tail surfaces and the fuselage gives a good idea of the characteristic shape of these airfoil sections.

Wind Tunnel Balances in the Aeronautics Department of Cambridge University

W. S. FARREN, *Cambridge, England*

(Received December 24, 1936)

SOME ten years ago a system of wind tunnel balances which possessed certain novel features was designed for the small wind tunnel which was then being constructed at Cambridge. This wind tunnel has a closed working section and an open return, with a cross section 28 in. wide and 20 in. high. It was intended partly for instructional purposes and partly for research, the latter mainly in conjunction with the experiments which are carried out in flight. These balances have proved to be satisfactory for both purposes, and balances on similar lines have been used fairly widely. The system of suspension gives the model a high degree of stability, enabling measurements to be made on stalled wings even when extended across the tunnel to within one-twentieth of an inch of the walls. In this way a close approximation to two dimensional conditions can be reached. The reduction of the results is simple and the interference of the supporting wires is small. The wires can easily be adapted to a variety of models whether of wings alone, or of complete airplanes, or of components such as bodies, etc. For these reasons the system has been used in the wind tunnels of several constructing firms.

An outline sketch of the essentials of the original balances is shown in Fig. 1, from which it will be seen that they deal only with lift, drag, and pitching moment. The determination of lift involves simultaneous measurements on two lift balances, L_1 and L_2.

On the main lift balance L_1 is pivoted at A a rigid triangular frame-work (1) to the lower corners of which the model is attached by wires (2), of which there are two pairs, their intersection defining an axis (X) about which pitching moments are measured. A second frame (3) is pivoted on frame (1) about an axis coincident with A, and to it can be clamped an arm (4) whose end also rotates about A. To any suitable point B on (4) a vertical wire (5) is connected, its other end being attached to the model at Y. $A\ X\ Y\ B$ is a parallelogram and the angle of attack of the model can therefore be read on the arc forming part of (3) and can be changed without entering the tunnel. The frame (3) is supported by the link (6) attached to the second lift balance L_2. Drag is measured by the bell-crank balance D which is connected to the frame (1) by a horizontal link (7). It is essential that the pivots of the lift balance L_1 shall be in the same horizontal plane as the pivot A of the frames (1) and (3), in order that the horizontal reaction introduced at A by the drag link (7) shall not influence the reading of L.

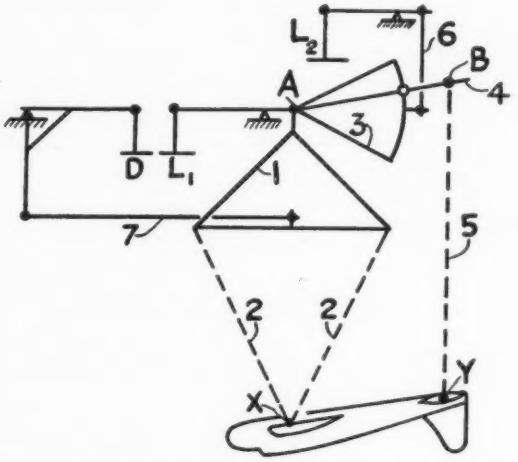

FIG. 1. Original system of balances. With this arrangement readings of both L_1 and L_2 are needed to determine lift. L_1 gives the Moment about X.

The reduction of the readings is simple and may be expressed in the form:

$$\text{Lift} = l_1 L_{w1} + l_2 L_{w2}$$
$$\text{Drag} = k D_w$$
$$\text{Moment} = a\ l_2 L_{w2}$$

where L_{w1} and L_{w2} and D_w denote the weights on balances, l_1 and l_2 are constants depending on the leverages of the balances, k is a number which depends on the distance $A\ X$ which is maintained constant by standardizing the lengths of the wires (2), and a is the fixed horizontal distance between the pivot A and the link (6).

The necessary geometrical conditions in order that the balances may be non-interfering are easily realized in practice. Experience has shown that the calibration factors remain constant, although the balances have been subjected to somewhat rough use over a number of years.

The system as arranged in Fig. 1 has two chief disadvantages. In the first place the aerodynamic forces tend to de-stabilize the main lift balance L_1. This could, of course, be overcome by artificial stabilizing, but the stabilizing effect would have to be varied with the wind speed. This has not caused any serious trouble, but it is undesirable. In the second place, the fact that read-

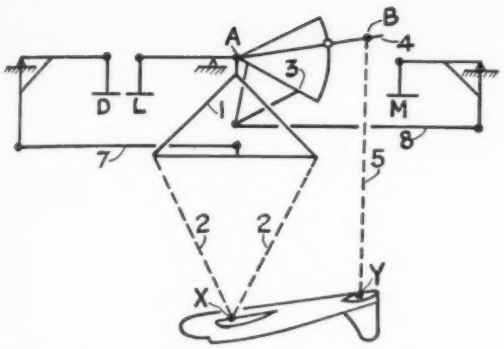

FIG. 2. Modified system of balances. The three balances give Lift, Drag, and Moment about X and are independent.

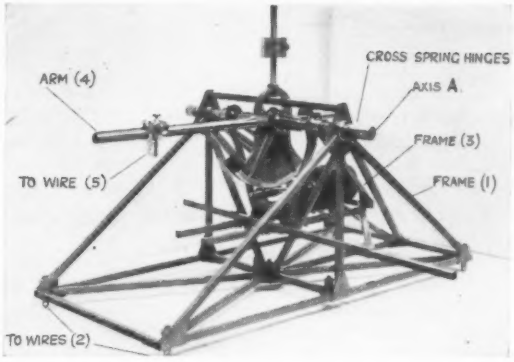

FIG. 3. Frameworks equivalent to (1), (3) and (4) of Fig. 2. The counterweights on (4) make it possible to avoid change of zero of the Moment balance when the angle of the model is changed.

ings of two balances are necessary in order to determine the lift is an appreciable handicap when the forces are fluctuating, and is a source of loss of time and possibly of error in reduction.

The construction during the last two years of another tunnel gave an opportunity for designing balances from which these defects have been eliminated. The new tunnel has a closed return circuit and is intended primarily for use with an open working section 35 in. in diameter. It can also be used with a closed working section. A complete description will be published in due course. The essential modifications which have been made to the scheme of balances shown in Fig. 1 are outlined in Fig. 2. The actual construction differs in many respects from Fig. 2, which shows the minimum alteration necessary to Fig. 1 in order to eliminate the defects mentioned above. It will be seen that this amounts simply to replacing the vertical link (6) (Fig. 1) connecting the frame 3 to lift balance L by a horizontal link (8) (Fig. 2) connected to a bell-crank balance which now measures only the pitching moment about the axis X. The whole of the lift is now measured by what was in Fig. 1 the "main" lift balance L_1. The three balances therefore now measure lift, drag, and pitching moment respectively. Moreover there is now no first order change in the attitude of the model as the lift balance swings thus avoiding the de-stabilizing effect mentioned above.

In order to realize this arrangement in practice it is necessary that the pivots of the balance shall be capable of taking horizontal as well as vertical forces. For this purpose the crossed spring arrangement now widely used is ideal. In the balances as constructed all pivots are made in this way, using generally two flat springs 0.5 in. wide by 0.004 in. thick, clamped at each end by a rectangular plate and a single No. 2 B.A. screw. It has been found that, provided the hole in the spring bears on the full diameter of the screw and not on the thread, a single spring shows no sign of distortion at 100 lbs. and has a failing load of about 300 lbs. These tests were made when the clamping screws had been tightened with an ordinary screw driver, using approximately the amount of force which could in practice be exerted during assembly of the pivots in the balances. As the working load of a spring is only of the order of 10 lbs. there is an ample margin. At the ends of the various connecting links throughout the whole system a single spring of the same kind is used. It is found that when the free length of the spring is about one-twentieth of an inch it can be used either in tension or in compression with an ample reserve.

The purpose of this note is mainly to describe the principle of the system. A full account of the other features of the balances will be published later, but they are briefly described below.

The photograph, Fig. 3, shows the parts which are the equivalent in Fig. 2 of the frame-works (1) and (3) and the arm (4). It will be seen that arrangements have been made to vary the angle of attack of the model by means of a worm and sector driven by an electric motor. This is mainly on account of the difficulty of reaching the balance when using an open jet. A celluloid scale of degrees is attached to the sector and is projected, considerably enlarged, on to a ground glass screen. The motor can be controlled and reversed by a variable resistance in series with a press switch.

The force measuring device for each component consists of two parts. There is in the first place a simple balance on which weights are placed more or less on the lines indicated on Fig. 2, but this is intended for use only with large weights. The smaller forces are measured by the deflection of thin flat springs attached to a link such as (7) or (8) in Fig. 2. (See Fig. 4.) The deflection of each spring unit is measured by mirrors, mounted on very light spring hinges, which reflect the image of the filament of an electric lamp on to a scale. One mirror indicates the movement of the end A of the link (7), for example. It therefore indicates the position of the balance mech-

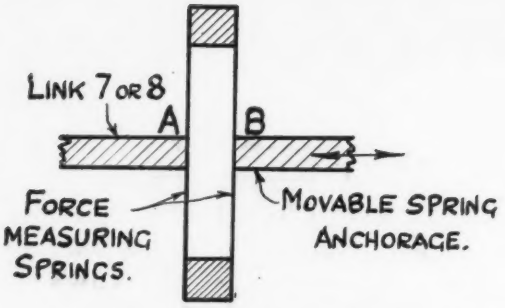

FIG. 4. Arrangement of spring unit for measuring small forces. The movements of the points A and B are indicated by mirrors and beams of light. Null readings are given by restoring A to a fiducial mark and reading B—approximate direct readings by fixing B and reading A.

anism in relation to the tunnel. The other mirror indicates the position of the movable spring anchorage *B*. When the image produced by the mirror attached to *A* is restored to a fixed fiducial mark, by moving the spring anchorage, the balance mechanism is in its correct position and the image produced by the mirror attached to *B* records the force applied by the spring. In order to avoid trouble from vibration, etc., the spring unit is relatively flexible, the maximum deflection between *A* and *B* being about one-tenth of an inch corresponding to a force of about 1 lb. The arrangement can also be used to give an approximate direct indication of the force by leaving the anchorage *B* fixed, when the image produced by the mirror attached to *A* indicates directly the force applied to the link. This, however, involves an appreciable displacement of the balance mechanism so that the measurement is not an accurate one, but for many purposes it is very convenient. It shows, for example, the way in which the forces vary when the angle is changed. It is particularly valuable when dealing with forces which fluctuate.

The author's experience with electromagnetic damping in the high-frequency balance developed for recording the reaction on a wing whose angle of attack is changing rapidly (A.R.C. Report, R.&M. 1648) led him to adopt it for these balances. A copper vane moving between the poles of electromagnets is connected to each of the three components by means of levers which multiply the movement approximately eight times, using spring hinges of the type described above. This arrangement gives a very useful control of the damping with a relatively small expenditure of electric energy. A total of about 3 amps. at 12 volts produces critical damping with a model of average weight.

Some of the features described above are still under development, but the present indications are that they will prove to be successful.

In one respect the balances described may appear to be somewhat out of date, since they make use of wires for supporting the model, but there would be no real difficulty in substituting relatively stiff streamlined supports.

It is interesting to consider how far a system of balances of this type meets modern wind-tunnel requirements. Many workers have pinned their faith on a more elaborate system, measuring all six components, and there are undoubtedly advantages in such a scheme. Others prefer to use a simple lift, drag, and pitching moment balance, and to cope with the measurement of other components by separate balances of a simple type, capable of being adapted to the purpose in question. In the author's opinion the latter scheme is generally to be preferred.

There would probably be fairly general agreement with this view when the main work is the instruction of students. For industrial use, in connection with airplane design, the six-component balance has certain claims to preference particularly because a great part of the time involved in all wind-tunnel work is taken in rigging up and adjusting the model upon the balances. In practice, however, many measurements are required in work of this kind which cannot be given by any fixed system of balances. For example, hinge moments of control surfaces must be dealt with by a special rig in every case. Moreover it is often best to determine them by measurements on a large model of the surface in question, and to this work the scheme described above can in fact readily be adapted. Probably its main defect from this point of view is that it does not enable yawing moments to be determined when the model is attached in the normal way. There is, however, little difficulty in rigging up the model on its side, particularly when, as is often the case, it consists only of the central body with tail organs.

There seem to be even stronger reasons for preferring a simple lift, drag, and pitching moment system when the main work is research. Here the type of experiment varies so greatly that no fixed balance system is likely to meet all requirements. Probably the most convenient compromise is to arrange so that the whole balance can be removed from the tunnel on rails, or, as is done in the 24 ft. tunnel at the Royal Aircraft Establishment, on a lift, replacing it by a frame-work to which can be attached whatever special balance may be needed.

Fifth Annual Meeting of The Institute of the Aeronautical Sciences

THE Fifth Annual Meeting of the Institute of the Aeronautical Sciences Inc. was held in the Pupin Physics Laboratory of Columbia University on Thursday, January 28, 1937 having been adjourned from January 27. Dr. George W. Lewis presided in the absence of Glenn L. Martin, President of the Institute. Lester D. Gardner acted as Secretary.

The reading of the minutes of the previous annual meeting was omitted with the approval of the meeting as they had been published in the Journal.

The Annual reports of the President, the Treasurer and the Secretary were read and duly approved.

The President's Annual Report

The progress made by the Institute during its fourth year should be gratifying to the membership. The Institute has been placed on a sound financial basis and it has been operated within its budget. Heretofore, the principal source of income, in addition to dues, has been from Benefactors and from advertising in the Journal. This year, through the creation of Corporate Memberships, it has been possible to conduct the affairs of the Institute without any income from these sources.

Corporate Membership. Immediately after the last Annual Meeting, your Council created a new grade of membership to be open to those companies engaged in aeronautical activities which wished to cooperate in the publication of the Journal of the Aeronautical Sciences, the holding of meetings in various cities, and the provision of a service to aeronautical specialists similar to that which is rendered by other professional societies, both here and abroad. It was brought to the attention of the Council that aeronautical companies preferred to contribute to the publication of the Journal by giving directly rather than through advertising, which required a considerable expenditure by the Institute. Through the dues received from Corporate Members, the Institute has been able to publish an enlarged Journal. Also, it has been able to maintain a small staff so that such a large amount of service would not have to be rendered by members.

Awards. The brothers and sister of Lawrence B. Sperry established this year an award in his memory for the greatest contribution made by a young man to the advancement of aeronautics during the year for which the Award is presented. Each year, $1,000 will be added to the Award Fund until it amounts to $10,000. Meanwhile, sufficient funds will be provided to give $250 and a certificate annually to the recipients.

The Institute appreciates being made the custodian of this Fund and will administer it faithfully.

Associate Fellows. There has been some confusion regarding the term MEMBERS since the Scientific and Engineering Members were grouped together under that grading. As all those who have been graded as MEMBERS have passed rigid requirements, the Council decided, after consulting with the Advisory Board, that it would make the grade more distinctive if this group were known as Associate Fellows. Since new Certificates of Membership were being prepared, it was decided to adopt the new name and rely on the support of the membership to confirm the action at the Annual Meeting.

Meetings. During the year many meetings of importance have been held. Of particular interest was the new affiliation with the American Association for the Advancement of Science which holds what are probably the largest scientific meetings in this country. At the A.A.A.S. meeting in Rochester, N. Y., on June 17th, the Institute joined with the American Association for Photogrammetry and held a session on aerial photography which was well attended. At the Atlantic City Meeting on December 29th Mr. T. P. Wright and Mr. Igor I. Sikorsky presented papers at the Institute's session which were widely quoted in the press.

In cooperation with the American Institute of Physics a program on "The Contribution of Physics to Aviation" was broadcast from the air over the Columbia network on October 30th.

The New York Museum of Science and Industry, wishing to extend its aeronautical section, invited the Institute to hold several meetings in its auditorium. Dr. Lewis, Dr. Zand, Dr. Arnstein, and Mr. Sikorsky addressed the four meetings held.

On June 26th a luncheon was given in honor of the British and French entrants in the International Championship Model Airplane Meet held in Detroit.

The Pacific Coast Section of the Institute has been very active during the past year. Five meetings have been held with large attendance.

These, together with the Annual Meeting held at Columbia University, indicate the broadening of this phase of the Institute's activities.

Daniel Guggenheim Medal. The Institute was invited to become a joint sponsor of the Daniel Guggenheim Medal with the American Society of Mechanical Engineers and the Society of Automotive Engineers. These societies graciously decreased their representation so that the nine directors of the Medal Fund would represent the three organizations equally.

The Institute was designated to present the Medal for 1936. As Dr. George W. Lewis, the recipient of the Medal for the year, was a Vice President and a Fellow of the Institute, the Council decided to hold a formal dinner in his honor. The heads of the government departments having an interest in aeronautics, as well as representatives from the air ministries of England, France, Germany, and Italy, attended and paid their tributes to the achievements of the guest of honor. In connection with the presentation, a request was made to England, France, Germany and Italy to prepare motion picture films of the new laboratories and wind tunnels and to show some of the work they were doing. Each country responded and an afternoon meeting was held, the A.S.M.E. and S.A.E. cooperating, at which the films were shown for the first time.

Index. The Works Progress Administration has continued to provide workers for a still larger program of indexing aeronautical publications. Between fifty and seventy-five people have been actively engaged in adding to the 400,000 references which are now in the Index. The plan for this year calls for the preparation of about fifty bibliographies on aeronautical subjects which are to be furnished without charge to governmental departments, laboratories, libraries and aircraft companies. The work is progressing and, when funds are available for processing, these bibliographies will be issued.

Foreign Members. Through the invitation of the Lilienthal-Gesellschaft, the new German aeronautical scientific society, the Secretary of the Institute was able to visit members of the Institute in Germany, Italy, France, and England. In Germany he found a growing appreciation of the services rendered to foreign visitors who come to the United States. In Italy our

distinguished member, General Crocco, gave a luncheon at which a group of famous aeronautical scientists paid their compliments to the Institute. In Paris, twenty members of the Institute, who are among the most outstanding aeronautical specialists in France, gave a luncheon and expressed their appreciation of the honor of membership in the Institute. In London, The Royal Aeronautical Society, The Royal Aero Club, and The Society of British Aircraft Constructors gave a dinner in Major Gardner's honor which was attended by many English members. Our Secretary has reported that the service rendered to foreign guests in assisting them during their visits to this country is greatly appreciated.

Student Members. Recognition should be given in any report of the year to the great interest in the Institute that is being taken by our Student Members in various schools. The affiliation with the Institute is appreciated as shown by the large increase in Student Membership.

Endowment. The Institute has not been as fortunate this year as it was last year when an anonymous donor informed the Council that he had included in his will a bequest to the Institute of approximately $500,000. The Institute is organized as a corporation operated for scientific purposes, "no part of the net earnings of which inures to the benefit of any private stockholder or individual and no substantial part of the activities of which is carrying on propaganda or otherwise attempting to influence legislation."

Therefore, all gifts to the Institute are exempt from gift taxes and bequests are exempt from all Federal estate taxes. Individuals are allowed to deduct from taxable income up to fifteen per cent of their annual income for gifts to the Institute and corporations can similarly deduct up to five per cent.

There are many members of the Institute who have acquired substantial rewards from their aeronautical experience. In considering the application of some portion of these funds toward the advancement of aeronautics so that others may be helped in the future, the Institute offers an exceptionally favorable opportunity. The Endowment Fund will aid the Institute in keeping up a high standard of service for the engineers and scientists engaged in aeronautical work. As a custodian of funds to be used for special purposes in aeronautics, donors will have the assurance of expert as well as conservative direction. There is no service to the Institute that can be rendered by members which would be more helpful than to make some gift or bequest which will perpetuate their work.

The Journal. With the Journal published monthly, members are now receiving an aeronautical magazine which has taken its rank among the leaders in scientific publications. The editorial excellence of the Journal has been due primarily to the efforts of Dr. J. C. Hunsaker, assisted by his associates at the Massachusetts Institute of Technology. The members of the Editorial Board have read critically many papers which have been submitted during the past year. To all who have contributed their services to the Journal, members of the Institute are greatly indebted and I thank them on behalf of the membership.

Conclusion. The reports of other Officers and Committees will deal with other matters of interest to members. Your President and the Council feel that during the past year they have followed the plan of the organizers and aimed at steady growth rather than superficial gains. As each year is added to the history of the Institute, those of us who participate in the many activities which it undertakes realize that such a scientific society was needed in this country and that the Institute fills a necessary place in the aeronautical field. To the Officers nd the Institute staff I express my personal appreciation for their excellent support of the President and know that the entire membership joins me in thanking them for adding another year of accomplishment for American aeronautics.

GLENN L. MARTIN

THE TREASURER'S ANNUAL REPORT

The Annual Report of the Treasurer for the fiscal year ending September 30th, 1936, is submitted as required by the By-Laws.

The Account has been audited with the approval of the Council by W. P. Schwebel of the Fairchild Aviation Corporation and his letter of transmittal, which I have submitted to the Council, states that the "accounts were found to be accurately kept and the statement reflects the financial condition of the Institute correctly."

The assets of the Institute increased this year from about Six Thousand Dollars to over Twenty Thousand Dollars. This was due to the receipts of Ten Thousand Dollars from the estate of Dr. S. A. Reed to endow the Award which bears his name and the first payment toward an endowment of Ten Thousand Dollars from the brothers and sister of Lawrence Sperry for the Lawrence Sperry Award. While these funds are restricted as to use they add to the stability of the financial statement.

Money given to the Institute for specific purposes is listed separately as "Restricted Funds" so that members may know the Institute's financial condition apart from such gifts.

The cash on hand and in the bank on September 30, 1936, was sufficient to cover the dues and subscriptions which were prepaid to January 1st. It indicates that the management follows its budget carefully.

As the most important item of expense of the Institute is the publication of the Journal its account is shown separately on the Operating Statement. As Corporate Members dues are paid for the support of the Journal instead of advertising, which formerly paid for the Journal costs, they are all charged as income for the Journal. As a large part of the expenses of maintaining the Institute offices and the salaries of the staff are incurred for the Journal they are shown as charged against the Journal. After the direct expenses of the Journal have been met it will be seen that there was Four Thousand Eight Hundred Fifty-one Dollars and Fifteen Cents left for supervision of the Journal.

Approximately half the Institute's income is received from the publication of the Journal and half from dues, after the cost of subscriptions have been deducted as required by the Postal Regulations.

It should be gratifying to members to note that even after charging off about One Thousand Dollars for depreciation and uncollectable accounts that the statement still shows a small amount of unexpended income.

This condition would not have been possible if all editorial contributions had not been provided without expense. Next year, with increased income that is expected, there should be provided an editorial assistant who would relieve the Editorial Board of some of its work.

The Institute has acquired during the past two years an asset which cannot be shown on a financial statement. The Works Progress Administration has provided over Fifty Thousand Dollars in services for the preparation of an aeronautical index which is the property of the Institute.

Your Treasurer is glad to state from his observation that the Institute is managed with economy and ability on a pay

Annual Balance Sheet

As of September 30, 1936

ASSETS		
Cash no Hand and In Bank for Institute Purposes		$4,482.17
Accounts Receivable		1,025.98
Investments of Restricted Funds		
The S. A. Reed Fund:		
U. S. Treasury Bond at Par Value	$10,000.00	
(Market Value September 30, 1936—$10,221.00)		
Accrued Interest Receivable on Bond	11.98	
Cash on Deposit for Award	229.55	
Total S. A. Reed Fund		10,241.53
The Lawrence Sperry Fund:		
U. S. Treasury Bond at Par Value	1,000.00	
(Market Value September 30, 1936—$1,022.10)		
Accrued Interest on Bond	1.20	
Cash on Deposit for Award	309.09	
Total Lawrence Sperry Fund		1,310.29
Office Furniture and Equipment	5,476.65	
Less — Reserve for Depreciation	2,096.69	
Net Total		3,379.96
Prepaid Expense		466.97
		20,906.90
LIABILITIES		
Accounts Payable		None
Reserves		
Reserve for 1937 Dues Paid in Advance	25.00	
Reserve for Unearned Member Dues	3,812.22	
Reserve for Unearned Subscriptions	623.31	
Total		4,460.53
Restricted Funds		
The S. A. Reed Fund	$10,000.00	
Net Income of Fund Set Up for Award	241.53	10,241.53
The Lawrence Sperry Fund	1,000.00	
Net Income and Donation Set Up for Award	310.29	1,310.29
Total Restricted Funds		11,551.82
Net Unexpended Income		
Unexpended Income — Balance September 30, 1935	4,633.12	
Net Unexpended Income for the Year ended September 30, 1936	261.43	
Total Net Unexpended Income		4,894.55
		20,906.90

as you go basis. It is rare in such statements to show "Accounts Payable—None."

I believe that the aeronautical profession may feel gratified that they have a scientific organization which is operated on such a reasonable budget.

SHERMAN M. FAIRCHILD

Statement of Income and Expenditures

for the Fiscal Year Ended September 30, 1936

INCOME		
Dues — Net after applying $3.00 per member for Journal	$5,045.62	
Initiation Fees	335.00	
Reprints and Miscellaneous Sales	175.99	
Reed Award for 1935 from S. A. Reed Estate — (see contra below)	250.00	$5,806.61
Supervision of Journal — (Net income from Journal operations — see detail below)		4,851.15
Total Income		10,657.76
EXPENDITURES		
Administration, Clerical and Accounting	5,920.58	
Rent	600.00	
Electric Expense	41.97	
Telephone and Telegraph	214.58	
Office Supplies	183.33	
Postage	521.38	
Printing	521.11	
Stationery	96.96	
Insurance	33.14	
Collection and Exchange	2.78	
Travel	507.00	
Entertaining	79.62	
Library	42.60	
Uncollectable Accounts	245.00	
Meeting Expense — Net Income $1,061, Expense $1,233.85	172.85	
Depreciation	844.99	
S. A. Reed Award — 1935 — to F. W. Caldwell	250.00	
Miscellaneous Expense	118.44	
Total Expenditures		10,396.33
Net Unexpended Income for Fiscal Year		261.43

Detail of Journal Income and Expense

INCOME		
Corporate Member Dues earned for period January 1 to September 30, 1936		$10,437.78
Subscriptions Earned		4,458.46
Advertising Sales (To March, 1936)		2,843.93
Total Journal Income		17,740.17
EXPENSE		
Agents' Commissions and Discounts	390.36	
Printing, Engraving, Postage, Rent, Salaries, etc.	12,463.66	
Circulation	35.00	12,889.02
Net Journal Income transferred to Institute Income Account		4,851.15

The Secretary's Annual Report

The report of the administration of the Institute can be short this year. Your Secretary hopes that the work of publication of a monthly magazine, organizing meetings, directing the Aeronautical Index, receiving and assisting members, particularly from abroad, and looking after the financial soundness of the Institute have been in themselves a report which is better than any lengthy representation.

The membership of the Institute has gained during the year as will be seen from the following figures:

Total Membership on January 1, 1936	1,305
Members elected during 1936	288
Members resigned during 1936	30
Members deceased during 1936	7
Members dropped during 1936	21
TOTAL MEMBERSHIP ON JANUARY 1, 1937	1,535

Division of Membership

	Foreign	*American*	*Total*
Honorary Fellows	1	5	6
Fellows	0	56	56
Associate Fellows	151	432	583
Technical Members	0	240	240
Pilot Members	3	63	66
Industrial Members	7	139	146
Temporary Members	0	5	5
Student Members	0	433	433
TOTAL	162	1,373	1,535

For many years there has been no fixed aeronautical event which celebrates December 17th, the birthday of the airplane. The Institute will hold a meeting and a dinner this year which the Council believes will be worthy of the anniversary. In the afternoon, a lecture to be known as "The Wright Brothers Lecture" will be given by a distinguished guest speaker who will be from the United States one year and on alternate years from a foreign country. It is hoped that an endowment of $15,000 for this lecture can be secured so that an honorarium of $250 may be given to guest speakers from the United States and $500 to those from abroad.

In the evening a dinner will be held in honor of the guest speaker. At this dinner it is planned to present the Sylvanus Albert Reed Award, the Lawrence Sperry Award, and any other aeronautical honors which may from time to time be

available. This will be the formal annual dinner of the Institute and will supplement the informal dinner held at the time of the Annual Meeting.

With four years of organization completed, the Institute should look forward to a steady growth. It is now recognized as the headquarters of aeronautical scientific and engineering activities in this country. We cooperate wholeheartedly with every other organization which has any interest in American aeronautics.

Looking ahead, there are no disquieting signs. If our membership continues to be as loyal and helpful as it has during the early years of the Institute's growth, we can proceed, confident that the Institute has achieved the aims of its founders.

LESTER D. GARDNER

The presiding officer appointed J. B. Taylor, S. J. Zand, and E. Burke Wilford to act as tellers of the proxies.

The Secretary reported that the members had been notified that the following amendment to the Constitution would be voted on at the Annual Meeting.

AMENDMENT

RESOLVED: That Section 1, Article II of the Constitution of the Institute of the Aeronautical Sciences be amended as follows:

Omit the word "MEMBERS" and insert in its place "Associate Fellows." Add the words "Corporate Members."

The Amendment to the Constitution was adopted as read.

The following members were elected by the meeting to act as Nominating Committee for 1937: Dr. George W. Lewis, Arthur E. Raymond, Glenn L. Martin, Dr. J. C. Hunsaker, D. W. Brown.

The Secretary then read the honors that had been conferred by the Fellows during 1936.

Honorary Fellows: Donald W. Douglas, Prof. A. Caquot of France, General A. Crocco of Italy, Prof. B. Melvill Jones of England, Dr. Hugo Eckener of Germany.

Honorary Member: Harry F. Guggenheim.

Fellows: Edmund T. Allen, Comdr. Garland Fulton, Dr. William Hovgaard, Eastman N. Jacobs, J. H. Kindelberger, Prof. Otto C. Koppen, Prof. Joseph S. Newell, Arthur E. Raymond, William B. Stout, and Prof. S. Timoshenko.

Ralph H. Upson for the Nominating Committee presented the following nominations which were unanimously elected.

Nominations for the Council to serve 3 years: E. E. Aldrin, Preston R. Bassett, Leroy R. Grumman, Juan Trippe.

For the Advisory Board: Edmund T. Allen, Charles F. Barndt, Lyman J. Briggs, Vincent Bendix, V. E. Clark, James H. Doolittle, W. R. Gregg, Hall L. Hibbard, James H. Kimball, Arthur Nutt, I. Machlin Laddon, John K. Northrop, A. E. Raymond, Gerard F. Vultee, J. H. Kindelberger, C. L. Egtvedt, Alexander Klemin, Grover Loening, H. J. E. Reid, and O. Westover.

The Secretary announced the names of the recipients of the *Sylvanus Albert Reed Award* and the *Lawrence Sperry Award* for 1936.

The *Sylvanus Albert Reed Award* for 1936 to Professor Edward Story Taylor *"For the development and practical application of the dynamic vibration absorber for aircraft engines."*

The *Lawrence Sperry Award* for 1936 to William Curtis Rockefeller *"For the application of Aerodynamics and Meteorology in determining the optimum flight path in air transport operation."*

The report of the Student Affairs Committee was presented by the chairman, George W. Haskins. It was referred to the Council for consideration.

The Secretary reported that the Council had met on the previous evening and nominated officers of the Institute for 1937 and authorized the Secretary to cast one ballot for the nominees at an adjourned meeting of the Council to be held simultaneously with the Annual Meeting. The Secretary stated that he had followed the instructions of the Council and declared the following officers elected:

Officers for 1937: President, Clark B. Millikan; Vice Presidents: Sherman M. Fairchild, Jack Frye, Dr. George W. Lewis, E. E. Wilson, T. P. Wright; Treasurer, Elmer A. Sperry, Secretary, Lester D. Gardner.

Dr. Lewis called the newly elected President of the Institute, Dr. Clark B. Millikan, to the chair.

Dr. Millikan in accepting the presidency said:

"I am profoundly grateful and conscious of the honor you have done me in asking me to serve as President of the Institute for the next year. I also feel very deeply the responsibility which is associated with this honor. I was fortunate enough to be one of the group which, largely as a result of the inspiration of Dr. Hunsaker and Major Gardner, met five years ago to organize this Institute. At the time I felt very strongly the great importance of the role which we all believed such an organization could play in the development of American aeronautics. I suspect that none of us then realized how rapidly the Institute would begin to approximate to the ideals which we held for it. The Journal has become one of the most valuable and important aeronautical publications in the world. The Skyport, the physical center and heart of the organization, has steadily grown more and more into a true spiritual center of our aeronautical life. These annual meetings have continuously increased in significance, both from a technical point of view and also, as seems to me still more important, as an occasion when all of us who have been infected with the virus of flying can get together and find out at first hand what we have been doing during the last year.

"But in spite of this glowing picture of achievement the problems of the Institute are far from completely solved. Much remains to be done in establishing more firmly and permanently the Institute's present position and in extending its usefulness to the aeronautical world still further. The interest and cooperation of the members and especially of the Advisory Board, Council, and officers have in the past been remarkable. I am sure that they will be continued in the future, and you may be sure that I shall do everything in my power to aid and support them."

The President expressed the appreciation of the Institute to Columbia University and especially to Professor George Pegram for the use of the Pupin Physics Laboratory building and the Faculty Club for the Annual Meeting and the Annual Dinner. It was voted to express the appreciation of the Institute to Columbia University and Professor Pegram. The meeting then adjourned.

Fifth Annual Dinner

The Annual Dinner of the Institute of the Aeronautical Sciences was held at the Faculty Club of Columbia University on Thursday, January 28, 1937. Three hundred and eighty members and guests attended.

Charles L. Lawrance as toastmaster introduced Dr. Clark B. Millikan, the newly elected President of the Institute, who expressed his appreciation for the honor of being selected to direct the affairs of the Institute for 1937.

The Sylvanus Albert Reed Award was then presented to Professor E. S. Taylor of the Massachusetts Institute of Technology for *"a notable contribution to the aeronautical sciences."* Dr. Millikan asked Latham G. Reed, the brother of the donor of the Award, to present the certificate and check for $250.

The Lawrence Sperry Award was presented for the first time. The recipient, W. C. Rockefeller of the California Institute of Technology, received the certificate and check for $250. Mr. Lawrance told of the work of Lawrence B. Sperry in whose memory the award has been endowed by his brothers and sister.

Donald L. Brown took over the duties of toastmaster and introduced several speakers who talked on *"Aviation Abroad—Impressions of Returned Travelers."* Arthur Nutt spoke regarding the situation in Russia; Dr. Millikan gave his impressions of German aviation, telling of his visits to the leading aircraft factories and the new methods in use in aircraft construction; T. P. Wright told of his visit to the Paris salon and of French aeronautics; Dr. S. J. Zand made a brief survey of the progress of aviation in Italy; James B. Taylor spoke on the recent advances in aircraft construction in England, and Bruce Leighton told of his experiences in flying over airlines in the Far East.

The concluding feature of the evening was a symposium on the Multi-Bellied Beta, by Charles L. Lawrance, Dr. J. C. Hunsaker and Luis de Florez. Mr. Lawrance delved into history to explain the origin of symbols and in a learned discourse disclosed the necessity of having a symbol which was the opposite of the conventional O. K. Dr. Hunsaker then demonstrated the mathematical significance of the new addition to scientific symbols by using it in formulae of many types. With this erudite foundation Mr. de Florez unveiled for the first time the device he had constructed to show the permutations and combinations of the Multi-Bellied Beta (which in popular slang represents the well known "Bronx Cheer"). The machine was carefully calibrated by anemometers, thermometers, wind speed indicators, pressure gages and vectorial direction finders. When demonstrated it gave variations of the new Beta including a squeak representing the square root of minus Beta. For his invention Mr. de Florez is being considered for many distinguished awards which may result in his receiving the symbol which will prove so essential in all engineering work of the future.

Dr. Clark B. Millikan

Dr. Clark B. Millikan, who was elected President of the Institute for 1937, was born on August 23, 1903, in Chicago. He is the eldest son of Robert A. and Greta B. Millikan. His father is chairman of the Executive Council of the California Institute of Technology and received the Nobel Prize in Physics in 1923 for isolating and measuring the electron and for photo-electric researches.

After attending the University of Chicago in 1919, he spent four years at Yale University, graduating in 1924 with the degree of Ph.B. While at Yale he became a member of Phi Beta Kappa. In 1928 he received the degree of Ph.D. in Physics and Mathematics from the California Institute of Technology. From 1924 to date he has been engaged in teaching aeronautics at the California Institute of Technology, at present being Associate Professor and in charge of wind-tunnel testing. He designed and supervised, in cooperation with Dr. A. L. Klein and Dr. Th. von Karman, the construction of the Guggenheim Aeronautical Laboratory at the California Institute of Technology. Dr. Millikan is a Lieutenant in the U. S. Naval Reserve, a member of the A.S.M.E., the Soaring Society of America, and other societies. He holds a private pilot's license and a soaring license.

Last year he was a guest speaker at the Lilienthal Society's Annual Meeting in Berlin. He is the author of many papers on hydrodynamics, theoretical and experimental aerodynamics, and aerodynamics of the airplane.

Dr. Clark B. Millikan

Book Reviews

Aircraft Engines, by ARTHUR B. DOMONOSKE AND VOLNEY C. FINCH, John Wiley & Sons, Inc., New York, 1936, 342 pp., 79 figs., $3.75.

This book is intended to be a treatise on the fundamentals of the internal-combustion engine as applied to aircraft. The treatment is limited to the subjects of elementary thermodynamics, fuel and combustion, cooling, supercharging and engine testing. In support of the theoretical treatment, data are presented in the form of tables and curves based on aircraft-engine practice.

The material presented is largely a compilation of opinions and data from previously published writings. It is easy to recognize excerpts and figures from N.A.C.A. reports, the S.A.E. Journal, the Air Service Engineering Handbook (of 1923), and from the works of H. R. Ricardo and D. R. Pye. While these sources are mentioned in the bibliographical references, one regrets that many figures and a considerable amount of almost-direct quotation are not specifically identified. It is particularly unfortunate that such wide use has been made of the published work of Mr. D. R. Pye, a member of the I.Ae.S., without adequate acknowledgment.

While the sources from which the material of this book originates are generally accepted as authoritative, the organization and arrangement are so poor that in many cases the value of the original treatment is lost. Especially weak are those portions of the book which deal with the thermodynamics of the fuel-air mixture and with the processes of combustion. The book would have been greatly strengthened if use had been made of the results of recent research on the thermodynamic properties of fuel-air mixtures, and on the character of combustion and flame propagation as revealed by high-speed photography.

C. FAYETTE TAYLOR
Massachusetts Institute of Technology

Engineering Aerodynamics, by WALTER STUART DIEHL; The Ronald Press Company, New York; 1936, 556 pages, ill., $7.00.

In the completely revised edition of this work, first published in 1928, the author has assimilated an immense quantity of material into one valuable book which should be a sound addition to the library of all aeronautical engineers as well a text to students in applied aerodynamics. The great number of figures, most of them new, show a tedious but careful anaylsis of a vast amount of data which is in keeping with the general tenor of the text. Tables of experimental data are also included. It is apparent that the author has attempted to make this as up-to-date and modern as possible.

Following an introductory chapter on definitions and symbols, the elements of fluid mechanics are discussed briefly. The next chapter offers a treatment of applied wing theory which deals with induced drag of monoplane, biplane, and triplane combinations. A complete group of curves are given showing the relation of Munk's span factor with various span ratios, gap-span and aspect ratios. The chapter concludes with a typical discussion of moment coefficient, span loading, and relative loading of biplane wings.

An important treatment of wind-tunnels and wind-tunnel tests takes up the case of Reynold's Number, its calculation, and its effect on test results. Wind-tunnel boundary interference and correction factors are discussed. The author then considers airplane and airfoil model tests and the relationship of the measurement of lift, drag, and the various moments in regard to the customary ranges of their values usually determined. A sample calculation of performance from the results of a model test is made.

The chapter dealing with airfoil data is up-to-date and complete in its treatment of variations of airfoil characteristics. Recent technical articles and N.A.C.A. data have been digested and presented in an easily usable form. More important airfoil sections are compared. Types of flaps and other high lift devices are described and their aerodynamic characteristics are noted in graphical or tabular form. Some effects of flaps on performance are given.

A very thorough study of static and dynamic stability and control occupies almost a fifth of the text. Space does not allow them to be described here in detail. Outstanding discussions have to do with the effect of flaps on the horizontal tail surfaces, types of balanced controls, and flutter. Stability derivatives receive considerable treatment.

Parasite drag data are given in curves and tables for all types and shapes of objects which might be used by the aircraft designer. Particularly of value are the figures on the effect of wing surface finish, protuberances on the wing, nacelles on the wing, fuselages, aircooled engines, radiators, landing gear, and seaplane floats.

Six chapters follow which have to do with airplane performance and flight problems. The first reviews the general engine characteristics and then takes up the propeller problem from a standpoint of the application in design and performance of the airplane. Propeller theory and design are omitted, not being within the scope of the book. The effects of many variables relating to the application of the propeller and to airplane design are covered to a considerable extent and well presented in graphical form. Most of the data have been condensed from N.A.C.A. reports. The calculation of the power curves for use in performance estimation follow. This includes that for supercharged engines and controllable pitch propellers. Performance estimation is treated in considerable detail. Range and endurance are discussed at length as well as special flight problems such as take-off characteristics for many conditions and gliding flight with and without power. Some fundamental design considerations are given.

A chapter on seaplanes and flying boats takes up the fundamentals of float stability and float performance. A description of model test methods and the conversion to full scale of test results is included. Take-off calculations are explained.

A final chapter discusses flight testing and the reduction of performance data to standard conditions. The variation of climbing airspeed and rate of climb with altitude is of considerable interest.

Three appendices complete the book. The first presents approximate equations for the standard atmosphere and standard atmospheric relations for performance reduction. The remaining two give conversion factors for various units and useful mathematical formulae.

The book is written from the standpoint of the engineer and the presentation is clear and straightforward throughout. The immense condensation of technical data under one cover is presented in easily accessible curves and tables.

R. P. HARRINGTON
Brooklyn Polytechnic Institute

AERONAUTICAL REVIEWS

These brief reviews of recent articles on aviation subjects are published by the Army Air Corps for the information of its officers, and are printed here each month by permission of the Chief of the Air Corps.

Aerodynamics

Atmospheric Wind Tunnel of the Mureaux Company. Very rapid variation in the convergence compared with the divergence is said to give the air constant acceleration, and the test chamber is of rectangular section of the type for the semi-guided jet. Advantages of this type are compared with those of free and guided jets. Investigations undertaken in the tunnel include: aerodynamic measurement of the speed and direction of the air current; study of the speed and direction of the wake; visualization of flow by means of smoke and observation by means of lighting or stroboscope; stereoscopic photography of the streamlines of the smoke; dynamic measurements of six components at normal angle of attack and drift with the Denis-Gruson continuous recording balance; and study of stability around the center of gravity. Long description of tunnel. Les Ailes, November 12, 1936, pages 5-6. 4 illus.

A Convertible Wind Tunnel. H. Winter. High- and low-pressure tunnel of the Aerodynamischen Versuchsanstalt Goettingen. Dimensions were selected in such a way that most tests with sufficiently large models could be carried out in the open working section, a moderate compression up to 3 atm. being used only for tests in which the influence of the Reynolds number is of particular importance. The pressure can be reduced down to 0.3 atm. absolute. In tests with the open jet velocities for the 5.4 x 4.0-m. nozzle ranged from 42 to 104 m./s. and for the 7 x 4.7-m. nozzle from 35 to 88 m./s., but the motors may be operated to give higher output. Design of the tunnel as a whole is based on the principles of Professors Prandtl and Betz. Translated from Luftwissen, September, 1936. Aircraft Engineering, December 1936, pages 335-336. 3 illus.

Dr. Lanchester on Skin Friction. Abstract of paper presented before the Royal Aeronautical Society and discussion following. Aeroplane, December 2, 1936, pages 717-718.

German Open-Jet Wind Tunnel. Open jet of the DVL tunnel is elliptical in section, the horizontal axis measuring 23 ft. and the vertical axis 16 ft. 5 in. The section can be enlarged to 26 ft. 3 in. by 19 ft. 8 in. if required. Maximum speed of the air at the outlet nozzle is 155 m.p.h. Long description and brief comparison with the 24-ft. open-jet wind tunnel of the return-circuit type located at the Royal Aircraft Establishment. Engineering, December 18, 1936, pages 657-659. 11 illus.

Construction, Characteristics and Operation of Wind Tunnels. German, British and French wind-tunnel construction, open-jet and supersonic tunnels, wind-tunnel motors, tunnel size, characteristic coefficients and correction, problems of the open jet, and characteristics of the air current in regard to distribution of pressure and speed, uniform speed distribution, turbulence, and measuring equipment. V. D. I., August 8, 1936, pages 949-957. 11 illus., 2 tables.

Skin Friction in Aeronautics. F. W. Lanchester. Part played by skin friction in aeronautics. Abstract of paper presented before the Royal Aeronautical Society quoting only the important points in the two sections relating to the application of the author's theory at high and low Reynolds numbers. Engineering, November 27, 1936, pages 588-589.

Square-Edged Inlet and Discharge Orifices for Measuring Air Volumes in the Testing of Fans and Blowers. L. S. Marks. Results of an extended series of investigations on a simplified form of square-edged orifice. Discharge coefficients obtained are identical with those found in extensive German tests and adopted in the standard rules of the V. D. I. and by the International Standards Association. This agreement justifies the use of the coefficients for the large-sized ducts and the varieties of the velocity distribution found in fan discharge ducts. Substitution of inlet and discharge orifice measurements for pitot-tube traverses and the adoption of these coefficients in a fan-testing code would greatly shorten and simplify the process of testing a fan and make it more accurate. A.S.M.E. Transactions, November 1936, pages 593-597. 4 illus., 1 table.

The National Physical Laboratory. Research being undertaken in industrial testing, comparison of model and full-scale results in the Froude laboratory, and resistance due to waves and friction is reviewed in the first issue. The second deals with research in the William Froude Laboratory in regard to propellers and paddle wheels, and describes apparatus of the Aerodynamics Department in regard to wind tunnels and balances, method of supporting models in the compressed air tunnel, and a light electrical aerodynamic balance. Engineering, August 28 and September 11, 1936, pages 217-218 and 286-288. 2 illus.

The Work of the Institutes of Research. Results on fluid mechanics undertaken by the Institutes of Paris, Lille, Marseilles, Toulouse, and Strabourg and exhibited at the Paris Aero Show. Special reference is made to research on propeller vortices, a wing with a movable upper surface, and supersonic speeds, and to the Riabouchinsky reaction motor. Les Ailes, November 19, 1936, page 8. 3 illus.

Aircraft Design

The Problem of the Tailless Airplane and the Fauvel Flying Wing. C. Fauvel. Simple, light and strong form of construction obtained with this type of wing, latitude in centering, safety features of the design, trimming in bad weather, and landing are discussed. Various Fauvel flying wings described in detail include the A.V.2 light airplane powered with a 20-hp. engine, the A.V.3 glider, and the A.V.10 two-seater powered with a 75-hp. Pobjoy engine. Concluded. L'Aéronautique, October 1936, pages 205-213. 12 illus.

Some Remarkable Stalling Experiments. W. E. Gray. The angle at which the trailing edge meets the air has apparently a profound influence on the way in which a wing stalls, especially as regards whether it stalls first near the tip or near the center. A new theory of the stalling of wings is discussed which is said to shed new light on the stalling of yawed tapered wings. An account of wind-tunnel and full-scale experiments to check the theory is started in this issue and conclusions are given on the influence of sweepback and sweepforward of the T.E. on spanwise flow before the stall.

In the second issue, experimental results are quoted to show that a straight T.E. gives a straight flow right up to the stall and a back-swept T.E. gives an outward surface flow. Flow on the wings of the Buecker Jungmann, D.H. Dragonfly, a small Monospar, and a B.A. Swallow, studied in flight tests, is described.

In the third issue, further evidence is quoted and an explanation given for deep and shallow stalls. Results of flight tests to show the flow over the D.H. Hornet Moth, the Monospar, the D.H. Leopard Moth, and the B.A. Swallow are discussed. Flight, July 16 and 23 and September 3, 1936, pages 94-97, 120-121, and 250a-250d. 22 illus.

Heavy Bombers. Doubt as to whether the heavy bomber is really worth while as a class is expressed in a short editorial referring to a recent Breguet article in Les Ailes. Mr. Breguet argues that military aircraft should now tend to become more and more alike in their geometry, only the actual dimensions being different. The high speed bomber of the future will be an airplane of approximately 22,000 lb. gross weight, with a wing area of only 650 sq. ft., an engine power of around 3000 hp., a speed of 300 m.p.h., a range of 1000 miles with a bomb load of 3000 lb. Brief. Flight, December 3, 1936, pages 591-592.

The original article entitled "A Common Technique for All Airplanes to Obtain Highest Speed." Les Ailes, November 26, 1936, page 5.

Flight in the Sub-Stratosphere. J. C. Edgerton. Meteorological, physiological and psychological aspects of the problem are referred to in a discussion by the Chief of the Stratosphere Section, Bureau of Air Commerce. Possibilities in the design of pressure compartments are taken up in regard to structural problems, sealing, and ventilation controlled by CO_2 content. Such development of a pressure compartment is said to permit of air-transport flights to 25,000 ft. Reference is made to present tests at Wright Field which revealed that the increased weight of windows ceases to furnish the anticipated difficulty. S.A.E. Jour. (Transactions), pages 484-486.

How Fast? N. B. Moore and W. C. Rockefeller. Ultimate high speed which could be reached at any altitude by an airplane designed for ultimate performance at these altitudes. Formulas are given for cost of speed at altitude, effects of increasing altitude, altitude and parasite drag, sound velocity and speed, induced drag, total cost of speed at altitude, and speed which could be obtained if the effect of compressibility were neglected. Continuation. Aviation, December 1936, pages 26-28. 6 illus., 1 table, 4 equations.

On Top. D. W. Tomlinson. High-altitude research undertaken by T.W.A. in a bimotored DC-1 and a single-engined Northrop Gamma. Engines, propellers, mixture control, carburetor air preheating, instruments and oxygen supply used are discussed. Duties of the crew, navigation problems, and results of a study of wind conditions and icing between 20,000 and 35,000 ft. are described. Aviation, December 1936, pages 21-24.. 4 illus.

Speed and Altitude in Aviation. L. Breguet. Maximum speeds and heights which it is possible for a commercial airplane to attain are calculated. Rev. de l'Armée de l'Air, October 1936, pages 1147-1161. 6 illus., 18 equations.

Study of a Type of Aero Motor for High Power. L. Poggi and A. Stringari. The aero motor described consists of airfoils with vertical axes placed at the periphery of a circumference of large radius, connected together in such a fashion that the whole can rotate around the axis of the circumference by means of a system of guides and rollers. The airfoils automatically acquire a suitable incidence. Aerodynamic theory and structural design are discussed. A second article by L. Poggi deals with the elementary aerodynamics of a wind motor for this type of gyroplane with particular regard to the problem of the increments of the rotor velocity. L'Aerotecnica, October 1936, pages 709-722 and 723-731. 7 illus., 1 table, 13 equations.

Tapered Wings. G. Lachmann. Discussion following presentation of paper before the Royal Aeronautical Society (published in the October 15 issue) is given with the author's reply. Flight, December 3, 1936, pages 613-614.

"Tomorrow's Airplane" Seen as Result of New Survey. Airplanes will be doubled in size with greater speed and comfort and will be powered by four engines according to conclusions reached by 15 aeronautical experts from the United Aircraft Corporation and M.I.T. Review of report with drawing showing the interior arrangements of the 20-ton transport plane of the future. Brief. Science News Letter, December 19, 1936, pages 390-391. 2 illus.

Stress Analysis and Structures

The Aerodynamic Loads for Stressing a Wing. W. R. Andrews. Simplified methods which are based on the quarter chord as a reference instead of the C.P. The methods are said to have particular advantages when investigating twisted wings and the author estimates that such wings can be stressed in less than half the time provided the number of cases investigated is four or more, including a T.V. dive. Flight, Air-

craft Engr. Sup., July 30, 1936, pages 1-6. 7 illus., 5 tables, 17 equations.

Stress and Strain in a Thin Elliptic Cylinder under Internal Pressure. W. S. Brown. Distribution of tension, shearing force, and bending moment in an elliptic rod or in a thin elliptic cylinder of any eccentricity subjected to uniform internal pressure. Formulas developed. Engineer, August 28, 1936, pages 201-202. 5 illus., 4 equations.

Tail Loads in a Steady Dive. W. H. Miller and P. M. Magruder. Method of determining the equilibrium conditions in a steady dive, with special reference to the magnitude and distribution of the air load over the horizontal tail surfaces. Continuation. Aero Digest, November 1936. pages 40, 42-44. 11 illus., 10 tables, 18 equations.

Riveting Stress Distribution in Riveted Seams in Airplane Structures. Investigation of rivet forces and expansion of the cross section between rivets, and description of the rivet combinations used in airplane structures. References to reported investigations. V.D.I., August 15, 1936, pages 1007-1008.

Some Methods Used in the Static Testing of Aircraft Structures. E. W. Walker. Apparatus and procedure for testing stabilizer and elevator, a fuselage monocoque structure, and a loading edge rib. Methods outlined were successful in meeting specifications of the Navy Bureau of Aeronautics. Aero Digest, November 1936, pages 28-29. 5 illus.

Thin-Walled Structures. F. R. Shanley. Further interpretation of modern forms of aircraft construction on a weight-strength basis and views on future trends. Evolution of thin-walled structures from the solid-shell through the semi-panel, panel, geodetic, corrugated, cellular, tubular and corrugated tube is illustrated. The cellular is considered the most promising. Continuation. Aviation, December 1936, pages 29-31. 8 illus.

Tubular Cantilevers. Lt. Commander W. P. Roop. Data contained in recent papers by Lundquist are summarized in the form of a diagram. Cylindrical tube of unstiffened metal of uniform thickness with ends fully constrained to retain their circular form is discussed. The load is transverse and the reactions are those of a simple cantilever. Journal Franklin Institute, December 1936, pp. 737-741. 1 illus.

Fuselage Stiffness. J. Morris. Torsional vibration of a conically tapered shell fixed at one end and carrying a mass of appreciable moment of inertia at the free end. The results of the investigation may be applied to the case where the rear portion of an airplane fuselage is in the form of a conically tapered shell, the tail unit being regarded as a mass of appreciable moment of inertia at the end. Flight, Aircraft Engineer Sup., November 26, 1936, pages 33-34. 3 illus.

Tapered Wing Geometry. H. Parkinson. Solution of the problem of intermediate rib profiles by the combination of calculation and draftsmanship. Flight, Aircraft Engr. Sup., August 27, 1936, pages 11-12. 5 illus., 2 tables.

Thin Sections in Torsion. W. J. Goodey. Direct stresses developed in open sections with one end subject to constraint. The condition necessary for these direct stresses to be developed is that some cross section of the tube remains plane when a torque is applied and it is assumed that this condition is obtained by building-in one end to a rigid wall. Aircraft Engineering, December 1936, pages 331-334. 6 illus.. 37 equations.

Aircraft

Civil Types in Paris. The 40-passenger Farman F.224 was the only representative of the really large commercial airplane in the Show. Comments are given on the F.224, the Leo H.246 and 47 (models only exhibited), the Amiot 341, the Russian A.N.T. 35 and 25, seven Caudron-Renault airplanes, the Praga E.210 of the Ceskomoravska Kolben Danek S.A., the Bibi-Be 550, the Mignet H.M. 18, 19 and 16, and other airplanes. Photographs and drawings of interesting features of these airplanes are included. Flight, November 19, 1936, pages 552-556. 17 illus.

An Engineer at the Paris Show. H. J. Pollard. Interesting structural features of the Continental aircraft exhibited are discussed with special reference to flush riveting, freedom from surface buckles, superior French design of windscreens, progress in spot welding (shown by the Sciaky Company), construction of the Fokker G.I., the Russian exhibits, operation of doors closing bomb shells and undercarriage openings, and the Potez exhibits. To be continued. Flight, Aircraft Engineer Sup., November 26, 1936, pages 29-32. 2 illus.

Military Types at the Show. Single and multi-seaters capable of 300 m.p.h., high-speed twin-engined monoplanes of considerably small size, and the predominance of military machines are important features of the Paris Aero Show. Considered purely as a design, the Koolhoven F.K.55 is said to be the most stimulating, and next in order comes the little Mureaux 190 C.1 with the propeller shaft geared up permitting a "canon" to be mounted above the crankcase whence it fires through the shaft. Comments on the design and armament are given for the Koolhoven F.K.55, Mureaux 190 C.1, Loire-Nieuport 250, Morane Saulnier 405, Soviet 2KB-19 high-speed stressed-skin, Dewoitine D.510, the Polish P.Z.L. P.24, and the Loire 46 single-seater fighters; Hanriot 220, Fokker G1, Potez 63, Bloch 131 bomber and the Breguet Vultur multi-engined multi-seaters; Czechoslovakian Letov S528, Polish P.Z.L. P.63, Mureaux 200A3 single-engined general-purpose airplanes; Romano 80, Morane Saulnier MS430, and Caudron Rafale training planes; and the Lioré et Olivier prototype of a military autogiro powered with a 350-hp. engine and thought to be the fastest autogiro in the air. Photographs and drawings of details of interest are included. Flight, November 19, 1936, pages 542-546. 24 illus.

On the Best Paris Show, Yet. C. G. Grey. Entertaining comments on the airplanes exhibited at the Paris Aero Show. The finish and workmanship of the Russian exhibits are said to be poor. This article is followed by one describing the exhibits of Amiot, A.N.F. Mureaux, Bloch, Breguet, Bristol, Brochet, Caudron, Farman, Fokker, Flauvel, Hanriot, Hawker, Kellner-Bechereau, Koolhoven, Leopoldoff, liore (autogiro and flying boats), Loire-Nieuport, Makhoune, Mauboussi, Mignet, Morane Saulnier, Polish, Potez, Romano, Salmson, S.C.A.L. S.F.E.N., S.F.C.A., Czechoslovakia, Russia, Volland, and the French Air Ministry. Photographs and drawings of interesting details and a table of specifications are included. Aeroplane, November 18, 1936, pages 641-663, 667. 49 illus., 1 table.

The Fifteenth Paris Aero Show. The Koolhoven F.K.55 pursuit airplane with a drawing of the drive to the propeller, the Rolls Royce Merlin engine, the Potez 63, and the Chauviere propellers. Designs described in detail. Continuation. Les Ailes, November 26, 1936, pages 3, 8, 9. 5 illus.

The Fifteenth Paris Aero Show Was a Triumph of Speed and Armament. Commandant A. Langeron. Comments on the trend in military aircraft as indicated by the exhibits. Les Ailes, November 19, 1936, page 12.

Three From Abroad. The Koolhoven F.K. 50B. twin-engined bomber, Vought scout bomber, and Brown B-3 racer. Brief descriptions. Flight, August 27, 1936, pages 222-223. 4 illus.

The Paris Aero Show. Military aircraft types predominate, there being few of the large commercial types, and there is a trend towards the use of inverted vee engines. A few comments on the aircraft exhibited. Flight, November 19, 1936, pages 540-541. 3 illus.

Practical Points from Paris. Outstanding points in regard to field of vision on military airplanes, instruments, and radio exhibited at the Paris Aero Show are referred to. Flight, November 26, 1936, pages 570-572. 8 illus.

Canada

Foreign News in Brief. Canadian Car and Foundry Company will build Grumman and Burnelli aircraft under manufacturing rights to meet the requirements of those countries which have heretofore been dependent upon production in Britain and the United States. Brief reference. Aero Digest, December 1936, page 72.

Czechoslovakia

Visit to the Airplane Exhibits of Czechoslovakia. The aeronautic industry of Czechoslovakia was represented at the Paris Aero Show by a military airplane, four sport and training airplanes and a well-known engine. Exhibits of Letov, Ceskomoravska-Kolben-Danek, Benes-Mraz, and Zlinska are described. Les Ailes, November 19, 1936, page 9.

France

The Fifteenth Paris Aero Show. The exhibits described include those of Farman, Duralumin, Caudron-Renault, Hispano-Suiza, and Liore at Olivier, as well as some of the aviation equipment displayed. Les Ailes, November 19, 1936, pages 3, 5, 6. 9 illus.

The Fifteenth Paris Aero Show. H. Beaubois. The aircraft covered include: the Amiot 341, long-range high-speed mail plane; the A.N.F.-Mureaux 190-C1 single-seater pursuit and 200-A3 three-seater observation and reconnaissance: the Breguet 470 T transport, 462 B.4 multiplace fighter, and 521 Bizerte flying boat: the Caudron-Renault C.690; the Dewoitine D.510 low-wing pursuit, D.338 transport, D.371 single-seater high-wing pursuit and D.513 pursuit; the Farman F.224 four-engined transport, and Moustique; the Hanriot 184 and H.220 light multiplace defense; the Latecoere 301, and 521; the Liore et Olivier LeO.H.246 transport, LeO. 45 bomber, and LeO. 46 seaplane fighter, and the LeO. C.34 prototype autogiro; the Loire-Nieuport, Loire 46, and Loire 250 single-seater pursuits, 161 pursuit, Loire 130 observation seaplane, Loire 21 low-wing pursuit seaplane, Loire 70 seaplane, and Loire 102 transatlantic flying boat; the Morane-Saulnier 405 single-seater pursuit, and M.S.430 trainer; the Potez 63 military and 60 light sport planes; the Romano R.82-ET.2; Leopoldoff L.5; Mauboussin Hemiptere; Salmson Cri-Cri; S.C.A.L. F.B.31; S.F.A.N.-4; S.F.C.A. Taupin, and Maillet-Lignel 20; and Volland V.10. Characteristics and in some cases performance. Rev. du Ministère de l'Air, November 15, 1936, pages 1397-1427 and 1440-1441. 26 illus.

The Fifteenth Salon de Paris. The entire issue is devoted to the French aircraft exhibits including the following: (Long descriptions and drawings indicated by asterisk.) L'Aile Volante (Fauvel A.V.14); Albert; Bernard; Bleriot-Aéronautique (Bleriot 510 and Spad 922); Bloch (150, 131, 160, *220); Breguet (Fulgur, 462, gyroplane); Caudron (Aiglon, C.720, C.690, C.460, Goeland, *Typhon, C.561); Farman (*F.221, Moustique, *F.224; Gerin (*Varivol); Hanriot (*H.220, H.230); Kellner-Béchereau; Latécoère (302); Leroy-Luquet; Levat; Pierre Levasseur (*P.L.200); Liore et Olivier (*Le O.H.45, *46, **47, 246, 257, and the C.34); Loire Nieuport (*Loire 250, *Nieuport 160, *Loire 46); Mauboussin (*40 Hemiptère, Corsaire 120); Morane-Saulnier (**405, 350); Mureaux (**190 C.1 and Stipa-Caproni bomber); Potez (65, 452, 453, and prototypes *56E., **63); Romano (R.90, R.92, R.110 and Naval prototypes R.120, R.130); Dewoitine (D.338, D.513, D.514, D.620); Salmson (**Cri-Cri); S.C.A.L.-Bassou (*F.B.30); Amiot (144, *150 B.E., **341); S.F.A.N. (2, 4); S.F.C.A.-Lignel (Maillet 20, Lignel 20, 10); Volland (V.10); Air-Wibault; Zodiac (balloons). Specifications for airplanes, engines, and equipment are given in a supplementary catalog of 68 pages. L'Aéronautique, November 1936, pages 219-311. Many illustrations.

Kellner-Béchereau Experimental Airplane and Its "Aile a tiroir." A. Frachet. High lift is obtained by an unusual type of wing with a double profile in the prototype of a small single-seater light monoplane which is designed for simplified piloting. This wing is formed of two surfaces, one fixed and the other movable and arranged side by side. The airplane is powered by a 40-hp. Train engine and has a theoretical top speed of 160 km. per hour and a range of 3 hours. Long description. Les Ailes, November 12, 1936, page 3. 5 illus. 2 tables.

The Light Mureaux 190-C1 Pursuit Airplane. A Frachet. The monoplane is equipped with a Salmson 450-hp. engine and armament identical to that of high-powered airplanes, and its performance is comparable with higher powered airplanes. Its maximum speed is 500 km. per hour at 4000 m. and its range 2 hours 30 minutes. Long description of design, construction, and armament with a few details of the Mureaux 200-A3. Les Ailes, November 26, page 6. 2 illus.

The Morane-Saulnier M.S.405 and M.S.430 Airplanes. M.S.405 single-seater pursuit equipped with the motor-cannon Hispano-Suiza 860-hp. engine, and the M.S.430 training plane. The pursuit is considered capable of a maximum speed of 480 to 500 km. per hour, and a landing speed of 100 km. per hour, although definite performance figures are not given. Description of design and construction. Les Ailes, November 19, 1936, page 10. 3 illus., 2 tables.

Review of the Light Aircraft Exhibits. P. Desbordes. Sport airplanes and engines exhibited at the Paris Aero Show, including the Train and Ava engines, the Peyret Taupin tandem airplane, the Farman Moustique, Salmson Cri-Cri, and Leopoldoff Colibri. Les Ailes, November 19, 1936, page 15. 2 illus.

Varivol. Gerin Varivol airplane with a wing surface variable from 7 to 28 sq.m. Photographs only. Les Ailes, November 26, 1936, page 1. 3 illus.

Report of the Services Techniques Français on the "Pou-du-Ciel". Results of tests on a modified Pou-du-Ciel which did not satisfy the conditions required for a certificate. L'Aéronautique, October 1936, pages 202-204. 8 illus.

Technical Notes. Mureaux has constructed a novel type of bomber under a Stipa-Caproni license. The propeller is located in a tunnel contained in part of the wing and a speed of 400 km. per hour is predicted for the airplane. Brief reference. Les Ailes, October 29, 1936, page 3.

Views of French Military Airplanes. Photographs of the interior of the A.B.21 four-motored bomber showing the posts of the pilot, radio operator, and mechanics, the panel for the control of the engines, and the passage for reaching the motors in the wing. Rev. de l'Armee de l'Air. October 1936, pages 1187-1190. 5 illus.

GERMANY

The Do-20, a development of the Do-X now under way in the Dornier factory, will have eight 800- to 1000-hp. gasoline in-line or Diesel engines and a wing spread of 161 ft. A maximum speed of 180 m.p.h., a 155 m.p.h. cruising speed, and a range of 2486 miles are expected. Brief reference. Aero Digest, November 1936, pages 82, 84.

German Military Aircraft. P. M. Magruder and L. Zachdroff. Development of the German Air Force, its disposition and strength, and the attendant program of expansion and industrial mobilization of the German aviation industry are discussed. Details of the construction, armament and performance of the bombers and observation airplanes in active service are given including the Junkers Ju-52 and Ju-86, Dornier Do-23, Heinkel 111 heavy bombers, and the Focke-Wulf 58 and Henschel 122 observation planes. A total of 2,800 military planes is said to be in active service, including 800 heavy bombers, 600 light bombers, 300 fighter-bombers, 450 fighters, 450 observation, and 200 miscellaneous planes. To be continued. Aero Digest, December 1936, pages 24-27, 31. 9 illus. 3 tables.

Heinkel He 111 Bimotored High-Speed Airplane. All-metal low-wing 10-passenger monoplane with retractable landing gear and tail skid was designed for transoceanic mail service. The airplane is powered by two BMW VI 660-hp. glycol-cooled engines with retractable radiators. V. D. I., September 12, 1936, pages 1143-1144. 1 illus.

"Jungmeister" Single-Seater Trainer. Buecker Bue 133 training airplane has a maximum speed of 230 km. per hour and a rate of climb of 1,000 m. in 2 min. 40 sec. It is powered by a Hirth inline air-cooled 140-hp. engine. Brief description. V. D. I., October 24, 1936, page 1302. 1 illus.

The Latest Product of the Junkers Factory. Constructional details of the Diesel-engined Junkers Ju. 86. Photographs only. Aircraft Engineering, November 1936, p. 311. 5 illus.

On the German Aircraft Industry. C. G. Grey. A visit to the Junkers airplane and Diesel-engine plants, with a reference to the performance of the Ju-86 bomber and to the layout of the engine plant to avoid bombs released from an airplane. Trouble with the water jackets of the Jumo 205 Diesels is referred to. Many interesting photographs of the Ju. 86 accompany the article illustrating the inspectability, structure, interior, undercarriage, and the Jumo 205 engine with cowling removed. Continuation. Aeroplane, November 25, 1936, pages 683-690. 22 illus.

GREAT BRITAIN

Bristol Type 138 Monoplane. The 335-457-hp. stratosphere airplane of the British Air Ministry which set a new world altitude record of 49,967 ft. Details of the airplane and engine, pilot accommodations, pre-flight calculations, and pilot's sealed suit. Aero Digest, November 1936, pages 30-31. 3 illus. 1 table.

Air Ministry Official Notices. Instructions to ground engineers and private owners on essential modifications in regard to engine mounting on the Monospar S.T.25, diving speed of the Cierva autogiros C30P and C30A, removal of Townend rings from Genet Major engines, carburetion improvements to these engines, and design requirements for instruments and equipment. Aircraft Engineering, December 1936, page 343.

". . . And Such Great Names." Westland Army Cooperation monoplane now named Lysander. Photograph only. Flight, December 3, 1936, page 603. 1 illus.

A British Dive Bomber. Hawker P.V.4 described has a top speed of 215 m.p.h. when powered with a Pegasus X engine and is capable of dive bombing with a 1000-lb. projectile load. Flight, August 27, 1936, page 237. 2 illus.

Direct Take-Off Type Autogiros. In the two autogiros described the inertia of the rotor is used to give the initial vertical lift and a new type of two-bladed rotor is fitted which is inherently stable under all conditions, the pitch of the blades being automatically variable. When taking off the rotor is driven from the engine. The Weir single-seater light autogiro is fitted with a 4-cylinder inverted 50-hp. Weir engine which is also described. Engineering, July 31, 1936, page 129. 2 illus. Engineer, July 31, 1936, page 120. 4 illus.

The Four Winds. It is said that the first Bristol Hercules two-row sleeve-valve engine will be installed in a Fairey Battle medium bomber. Brief reference. Flight, December 10, 1936, page 624.

The Miles Peregrine. Phillips and Powis monoplane is powered by two Gipsy Six II 205-hp. engines, carries a ton of disposable load and has a top speed of 180 m.p.h. The airplane carries eight passengers and has pneumatically retracting undercarriage and split trailing-edge flaps. Performance, construction, and characteristics. Aeroplane, December 2, 1936, pages 721-722. 5 illus.

A Minor in Metal. Cygnot Minor, Great Britain's first completely metal-covered light airplane, is produced by C-W Aircraft. The airplane is of stressed-skin construction and has a top speed of 125 m.p.h. The prototype is fitted with a new Cirrus Minor 80-90-hp. engine. Description of the Cygnet and reference to a small twin-engined monoplane named the Swan which has been planned. Flight, December 10, 1936, pages 628-630. 11 illus. Aeroplane, December 9, 1936, pages 747-748. 6 illus.

The New Altitude Record. R. H. Weir. The Bristol 138A monoplane, the P.E.VI.S. engine; and the equipment used in reaching the height of 49,944 ft. and thus establishing a world altitude record. Choice of an airplane type, aircraft structure, selection of an engine type, engine details, propeller, pilot equipment, recording instruments, and the record flight are discussed and future plans referred to. Aircraft Engineering, December 1936, pages 327-330. 4 illus.

The New Autogiros. Advantages of the autodynamic rotor head of the new Weir-type of autogiro which jumps more than 20 ft. in altitude when starting. Description. Flight, July 23, 1936, pages 114a-114d. 16 illus.

New British Cabin Two-Seater. Wicko Wizard with converted Ford V-8 or Cirrus Minor engine has a top speed of 120 m.p.h. A few details. Flight, July 30, 1936, page 136. 1 illus.

Wickner's Latest. High-wing two-seater cabin monoplane driven by a 80 hp. converted Ford V-8 water-cooled engine. A few details. Aeroplane, July 29, 1936, pages 152, 157. 2 illus.

The Four Winds. A Hawker Hart with cockpit enclosures and with a Bristol Perseus sleeve-valve engine is being sent to Canada for test under low-temperature conditions. With a Bristol Mercury VIII engine, the Hart does 209 m.p.h. at 15,550 ft. and climbs to 17,000 ft. in 7 min. 23 sec. Controlled cooling is embodied. Brief reference. Flight, November 26, 1936, page 573.

The low-wing monoplane trainer (Gipsy Twelve) being built for the British Air Ministry by De Havillands has side-by-side seating, front and rear guns, and dual control. Brief reference. Flight, November 19, 1936, page 550.

Latest from Woodley. Peregrine light transport airplane, powered by two D.H. Gipsy Six II or Menasco engines, is said to be readily adaptable as a twin-engined training machine, or with armament as a military general-purpose airplane. Maximum speed is 180 m.p.h., cruising speed 160 m.p.h., and range 562 miles. Long description. Flight, December 3, 1936, pages 594-595. 4 illus. 1 table.

The Miles Mohawk British Long Range Light Monoplane. The new airplane built for Colonel Lindbergh differs from its predecessors in regard to the cockpits, landing gear, tail unit, and use of an American-built Menasco engine. Long description of the airplane. Aero Digest, December 1936, pages 30-31. 4 illus.

HOLLAND

The Koolhoven FK-55 Pursuit Airplane. A. Frachet. A Lorraine Petrel 860-hp. engine is located within the fuselage of the FK-55 behind the pilot and operates a group of two propellers turning in opposite directions. The maximum speed is estimated at 520 km. per hour and ceiling at 10,000 meters. The monoplane is constructed of wood. Long description. Les Ailes, October 29, 1936, page 3. 4 illus.

ITALY

Italian Military Planes. P. M. Magruder. Many practical results obtained from the experimental and research program under way at Guidonia are shown in the military and naval aircraft now being delivered to the Italian Air Force. This year 1500 bombers will be built and an increase is expected in 1937. Bombers are almost exclusively Caproni or Savoia Marchetti types, more than half of the flying boats or patrol planes also being of these makes. Latest Savoia bombers have unusual performance. The Breda 46, the Caproni Ca97, Ca101, Ca111, Ca133, the Piaggio P-16, and the Savoia S-72, S-79 and S-81 bombers, the Cant Z.501 light bombing flying boat, the Caproni 97-Hydro light bomber, Macchi, M.C.77 single-engined bombing and long-distance reconnaissance flying boat, and the Savoia S-55 torpedo or heavy bombing flying boat are described. Concluded. Aero Digest, November 1936, pages 22-24, 86. 9 illus. 1 table.

Ro. 37 Airplane for Strategic Reconnaissance and Combat. The two-place biplane described may be powered by either a Fiat A.30 R.A. water-cooled 550-hp. engine or a Piaggio P.X.R. air-cooled 700-hp. engine. When powered by the Fiat the airplane has a speed of 335 km. per hour at 3000 m. Range with normal load of 835 kg. and at a speed of 280 km. per hour is 1500 km. L'Aerotecnica, October 1936, pages 770-774. 5 illus.

Ro. 43 Catapultable Naval Seaplane for Reconnaissance and Combat. The two-place biplane described has a central float and is powered by a Piaggio 700-hp. engine. It has a maximum speed of 305 km. per hour at low altitudes and 316 at 2500 m. L'Aerotecnica, October 1936, pages 767-770. 4 illus.

JAPAN

The Four Winds. A machine is being constructed in Tokio which, it is said, will be capable of flying non-stop from Tokio to New York, a distance of 6500 miles. Brief reference. Flight, November 26, 1936, page 573.

Various Notes. Japan's best aircraft engineers have evolved a long-distance plane embodying new aeronautical principles. Its maximum speed approaches 145 m.p.h. and its cruising limit is 75 hours. Brief reference. U. S. Naval Inst. Proc., December 1936, page 1796.

U. S. A.

285 hp. Fleetwings "Sea Bird" 4-Passenger Amphibion. New four-passenger amphibion of stainless steel, fabricated by the shot-weld process, is powered by a 285-hp. Jacobs engine mounted above the wing. A retractable tail wheel can be used as a water rudder. The amphibion has a maximum speed of 150 m.p.h., a cruising speed of 135 m.p.h., and a cruising range of 450 miles. Design described. Aero Digest, November 1936, page 58. 3 illus.

Bellanca 28-70 "Flash." With a full cantilever wing and with a Twin-Wasp engine a new version of Mollison's transatlantic airplane is expected to have a top speed in excess of 300 m.p.h. and a range of over 5500 miles. Details given are those of the Flash in which Captain Mollison recently made a record flight across the Atlantic. Aviation, December 1936, pages 33-34. 6 illus. Aero Digest, December 1936, page 38. 2 illus. 1 table.

Ben Jones S125. Two-place low-wing monoplane described may be powered by a Menasco C4 125-hp. or C4S 150-hp. engine. When powered by the latter, the airplane has a maximum speed of 162 m.p.h. and a range of 680 miles. Aviation, December 1936, page 34. 4 illus. 1 table. Aero Digest, December 1936. page 42. 3 illus. 1 table.

Curtiss P-36 Pursuit Monoplane. Curtiss low-wing cantilever monoplane purchased for the Air Corps. A few details. Aero Digest, November 1936, page 36. 2 illus.

Douglas Twin-Engined Model DF Long-Range Flying Boat. New 32-passenger all-metal twin-engined flying boat described was designed for long-range transoceanic service. The airplane carries 1620 gal. of fuel which gives it a non-stop full-load range of 1500 miles at a cruising speed of 167 m.p.h. Maximum speed is 185 m.p.h. Aero Digest, November 1936, page 56. 3 illus.

First Place Winner in the 1936 Continental Aircraft Design Competition. Titan two-place high-wing monoplane designed by L. R. Biasell is powered by a Continental A-40 37-hp. engine. Features found in higher-priced airplanes are incorporated and yet the operating and maintenance costs are those of a small light craft. Description. Aero Digest, December 1936, page 50. 2 illus.

Frank Hawks Speed Plane. The semi-low-wing cantilever monoplane "Times Flies" is powered with a Twin Wasp R-1830 BG engine developing 1150 hp. and expected to give the plane a cruising speed of 340 m.p.h. and a maximum speed of 375 m.p.h. Description of airplane and instruments. Aero Digest. November 1936, page 54. 2 illus. 1 table.

New Flying Boat Project. A few details of the new Boeing 60-passenger transoceanic Clipper ship for Pan American Airways are mentioned. Aero Digest, November 1936, page 78.

XOZ-1 Gyroplane. Wilford pontoon-mounted XOZ-1 gyroplane, built for the Navy, can be considered a compromise between the airplane and the autogiro since it has a fixed wing which carries from 60 to 80 per cent of the load in cruising. Few details only. Aviation, December 1936, pages 34-35. 1 illus.

Corpulent Warrior. Close-up of the nasal arrangements of the Grumman SF-1 Naval scout showing the retractable landing gear and landing light in the fuselage. Photograph only. Flight, August 20, 1936, page 198. 1 illus.

Aircraft Manufacture

The DeHavilland Aircraft Works. Points of interest viewed during a visit to this plant. Engineer, December 11, 1936, page 636. 2 illus.

Design for Production. E. P. Warner. Review of the papers presented and discussion taking place at the S.A.E. Aircraft Production Meeting. To be continued. Aviation, December, 1936, pages 18-20, 62. 4 illus.

Aircraft Operation and Maintenance

Airplane Brakes. J. G. Thompson. Relining of Autofan brakes, troubles ordinarily experienced with hydraulic brakes, Bendix high-pressure disk wheels, and brake and wheel inspection. Maintenance methods. Continuation. Western Flying, December 1936, pages 21-23, 44. 3 illus.

The First One-Half Million Miles of Pacific Progress. D. Sayre. Start of the Pan American transpacific airline, maintenance schedules, training crews, system of navigation, weather forecasting, system of cruising control, and future prospects. Aviation, December 1936, pages 15-17, 43, 44. 7 illus.

Aircraft Performance Testing

Tests of Maneuverability and Instruments. F. Haus. Equipment developed by M. Bouny for recording the variables characterizing the movements of an airplane in flight tests, and the results obtained in research undertaken to determine the characteristics of stability and maneuverability of an airplane. The potentiometer type of recorder for wind vanes and controls, and the accelerometers and angular speed indicators used are described. L'Aéronautique, L'Aéronautique Sup., October 1936, pages 129-140. 17 illus.

Aircraft Instruments

The Constantin Wind Vanes and Automatic Control. M. Constantin. Descriptions of the Holmes compass and Smith automatic pilot, appearing in the August issue, are criticized and the devices compared with the Constantin wind vanes for automatic control of aircraft. L'Aérophile, October 1936, pages 236, 240.

A Fix from Altitude and Azimuth at Sea and in the Air. Captain R. de Aquino. Method developed by the author for working out a fix by combining the altitude of a celestial body with its simultaneous azimuth by a gyro-compass. United States Naval Inst. Proc., December 1936, pages 1727-1734. 2 illus.

Flight with Instruments. General A. Crocco. A physiological or psychological sense of bearings in space does not exist but there is a vestibular sense of accelations which, with exceptional natures, can lead to an indirect sense of the spatial position. Training of fliers for instrument flying. Rev. de l'Armée de l'Air, October 1936, pages 1085-1105. 8 illus.

Sensitive Altimeter. The Pioneer altimeter described is considerably more sensitive than the standard instrument and embodies a direct-reading barometric setting. The barometric setting device, in the form of a Veeder counter, is built into the lower portion of the dial distinctly separate from the altitude scale. Few details only. Aviation, December 1936, page 39. 1 illus. Aero Digest, December 1936, page 54. 1 illus. United States Air Services, December 1936, page 34. 1 illus.

Aircraft Accessories

CONTROLS

Locking Type Control Unit. Arens locking-type control unit for aircraft which can be used for either a locking or friction device by varying the strength of the spring. Few details. Aero Digest, December 1936, page 54. 1 illus.

Aircraft Carriers

Aircraft Carriers. C. Rougeron. Lieutenant Barjot's recent paper on aircraft carriers is criticized by the Chief engineer of the French Corps of Naval Constructors. The criticism deals with the types of aircraft to be carried, and the armament and speed of the carrier. Rev. de l'Armée de l'Air, October 1936, pages 1128-1146. 3 tables.

Equipment

Equipment. French instruments, pumps, magnetos, piston rings, landing gear, Seapak, starters, aerial photographic equipment, radio-screened spark plugs, flexible engine mountings, propellers, fuel hose, tail-unit vibration damper, and radio for aircraft. Specifications for these products are given in a special advertising section of the magazine. L'Aéronautique Supplement, November 1936, pages 50-68. Many illustrations.

Installation of De-Icer Equipment for Winter Airline Service. F. L. Hattoom. De-icing equipment used on TWA transports. Rubber overshoes on the leading edge of the wing and an investigation conducted by B. F. Goodrich Company and Cornell University are referred to. The propeller de-icer is described. Aero Digest, November 1936, pages 38, 86. 3 illus.

High-Altitude Flight Equipment

Physiology of Men in Flight. G. Schubert. Requirements of pilots in flight with references to conditions at high altitudes. Long article. Rivista Aeronautica, October 1936, pages 119-126.

Physiological Requirements of High-Altitude Aircraft Compartments. Captain H. G. Armstrong. Study undertaken at the Materiel Division of the United States Army Air Corps on the problem of maintaining personnel at high altitudes. The discussion covers the oxygen requirements, the carbon-dioxide problem, carbon monoxide and other noxious gases, temperature regulation, humidity control, ventilation, noise levels, and barometric pressure considerations. Aero Digest, November 1936, pages 25-28. 3 illus., 5 tables.

Miscellaneous Equipment

An Instructive Kiwi. Kronfeld ground trainer. Description. Flight, September 3, 1936, page 255. 2 illus.

A Neat Inspection Door. The Chobert door described pivots around its center on a spindle held in an arm of the door hinge. Flight, August 20, 1936, page 213. 7 illus.

A Substitute for the Split-Pin. Collis Griplex washer for locking pins in fork ends without split pins. Canadian design. Aeroplane, December 9, 1936, page 757. 1 illus.

Around the Galleries. Outline of British accessories and equipment represented at the Paris Aero Show. Flight, November 26, 1936, pages 584-585. 4 illus. "British accessories and some others." Aeroplane, November 18, 1936, page 666.

Buyers' Log Book. Hydro-degreaser, stretching jack with non-slip cog, Vari-Speed control for portable electrical tools and other small motors, Thor spray gun, and tubing data book. Few details. Aviation, December 1936, page 41. 2 illus.

Cable Shear. U B Shear for cutting fine strand airplane control cable. Few details. Aero Digest, December 1936, page 54. 1 illus.

Grip-Lock Bearings. Latest addition to the SKF line of antifriction bearings Few details. Aero Digest, November 1936, page 61.

The Mechanical Solution of Simultaneous Equations. J. B. Wilbur. Machine developed at M.I.T. for the solution of linear simultaneous equations with real coefficients. Theory upon which the machine is based, the machine as built, its operation, results obtained, and future investigations. Journal Franklin Institute, December 1936, pages 715-724. 4 illus.

Metals

Construction of the Empire Flying Boats. Metals used in the construction of these British flying boats. Brief Metal Industry, November 27, 1936, page 537. 1 illus.

A Cadmium-Zinc Alloy for the Protection of Airplane Wires. An alloy of 83 per cent cadmium and 17 per cent zinc has a melting point of 266°C. and advantages in regard to density, strength, uniformity, adherability, and appearance. It is unaffected by atmospheric conditions and its resistance to chemical attack even exceeds that of cadmium and zinc. A series of coatings of zinc, tin, copper-zinc, lead, aluminum, and cadmium were subjected to mechanical as well as chemical tests and this coating was selected for standard Italian practice. Brief. A. T. Z., October 10, 1936, page 493.

Acoustics

American Sound-Proofing in Europe. A few developments in sound-proofing aircraft in Europe referred to in an interview with S. Zand. Western Flying, December 1936, page 20.

Physical and Technical Fundamentals for Detecting Airplane Noises. E. Kutzscher. The airplane as a sound transmitter, reception of airplane sound, and construction of a noise detector. V. D. I., August 15, 1936, pages 995-1000. 11 illus.

Airships

The "Hindenburg"—Some Measurements. P. R. Bassett. "The Hindenburg is the quietest form of transportation now available." General account of a trip on the airship and measurements made in different parts of the airship on the noise level, vibration, and acceleration, showing why the airship is inherently unique and comfortable for passengers. United States Air Services, December 1936, pages 22-24. 1 illus.

Rocket Aircraft

Rocket Flight. J. P. Eames. The rocket engine and its advantages, fuels available, and a drawing of a proposed rocket aircraft upon which the author has been retained as an engineering consultant. Western Flying, December 1936, page 16. 1 illus.

Records

Digest of Recent Events. Glider sustained flight record made in Russia, Ingalls inter-city fast flights, British altitude record, Bjorkvall transoceanic flight, German experimental transoceanic flights, solo record made by Jean Batten, world flight by reporter in 18 days, and passenger service across the Pacific are briefly referred to in the first issue. In the second, Mollison's new sea record and the Paris-Hanoi mark set by the French pilot. Aero Digest, November and December, 1936, pages 72 and 69.

Propellers

Practical Uses of Propeller Brakes. R. B. Quick. The advantages are said to be an appreciable increase in speed in level flight when the propeller of a disabled engine is restrained from wind-milling in high speed, a reduction of landing speeds, and an increase in controllability, longitudinally and directionally, when the wind-milling propeller is stopped. Test results referred to in a brief discussion. Aviation, December 1936, page 25. 1 illus.

The Milner V. P. Airscrew. The variable-pitch mechanism consists of two separate and distinct parts, the pitch-changing mechanism and the pitch-control mechanism, which do not operate independently but are dependent for their operation upon different essential principles. The pitch-changing mechanism depends for its operation upon centrifugal force. The blades are linked by crankpins to a sleeve surrounding the propeller shaft, so that any twisting movement of the blades in their sockets must be accompanied by a sliding movement of the sleeve. The pitch-control member consists of a flywheel mounted on an extension of the propeller shaft. Long description. Flight, December 3, 1936, pages 608-609. 3 illus.

A Native-Born Airscrew. In the hydraulically-controlled Hele-Shaw variable-pitch propeller developed by the Bristol company, the pressure can be applied to either side of the operating piston instead of to only one side. The propeller also incorporates an over-ride device whereby the governor can be so adjusted that any pitch setting can be obtained at the will of the pilot. Brief. Aeroplane, December 2, 1936, page 728. 2 illus.

Engine Design and Research

Centrifugal Superchargers for Aircraft Engines, Operation and Power of the Engine-Supercharger Group at High Altitudes. R. Chiappulini. The dimensional relationships applied by R. S. Capon and G. V. Brooke to air compressors are discussed and the altitude factor is inserted over the temperature factor. A simple law is determined for the lift of the air taken in by the supercharger to connect the two elements, supercharger and engine, and to investigate their behavior at high altitudes. An average "statistics" law is suggested for the decrease of power with altitude for a supercharged engine. L'Aerotecnica, October 1936, pages 732-743. 6 illus., 1 table, 15 equations.

Cooling Aircraft Engines by Water Vapor. M. Précoul. Calculations of the cooling surface of wing condensers, and references to water separators and to experiments with a telescopic condenser developed for the British Royal Air Force. Rev. du Ministère de l'Air, November 15, 1936, pages 1378-1382. 1 illus.

Dead-Center Displacements and Stroke Variations in Radial Engines. F. Wilmanns. As a result of the attachment of the articulated connecting rod to the master rod in the radial engine the upper and lower dead centers are not equal to the time given by the cylinder number (crank position) and the stroke in the side cylinders differs from that in the top cylinder. As shown in the example given for a three-cylinder radial engine, dead-center displacement of the separate cylinders in regard to time, and the stroke differences in the side cylinders, as compared with the top cylinder, can be derived for equal clearance space in all cylinders from a diagram when the master rod length as well as the attachment radius and angle of the articulated connecting rod are given. V. D. I., October 31, 1936, pages 1321-1324. 4 illus., 4 tables, 6 equations.

Effects of Detonation on Oil Consumption. H. A. Everett and J. J. Mikita. Oil consumption increases with detonation whether the latter is induced by increasing the spark advance or by the use of low-octane fuels, and it increases with severity of detonation. The effect does not always vanish immediately with the cessation of audible detonation. Brief abstract of S.A.E. paper describing tests made at Pennsylvania State College. Automotive Industries, December 19, 1936, page 855. 1 illus.

Heat Loss in High-Speed I.C. Engines. W. T. David. Defect of the actual indicated thermal efficiency below the ideal calculated efficiency. The four possible explanations suggested to account for the fact that the defect is far less than 5 per cent for gaseous fuels and 5.5 per cent for liquid fuels are: that the ideal calculated efficiencies are too low; that the measured efficiencies overestimate the real performance within the cylinder of the engine; that the theory of the high-speed engine requires some modification or extension; and that heat losses during the explosion-expansion stroke are much overestimated. Each of these explanations are discussed in turn. Engineer, December 25, 1936, pages 675-677. 1 table.

Supercharging with Some Notes on Its Application to Compression-Ignition Engines. L. Pomeroy. A substantially uniform volumetric efficiency over an engine speed range of at least 3-1, minimum power to drive, durability and reliability equal to the engine, minimum oil consumption, silent operation, compactness and light weight, low service and manufacturing costs, mounting and drive, and effects of supercharging. Comparison of the centrifugal. Roots and Vane eccentric-rotor types of superchargers. Automobile Engineer, September 1936, pages 355-359. 6 illus.

Airplane Flight to and in the Stratosphere. R. J. Smith. Use of an oversized or superdimensioned engine so large that it would give the desired power at wide-open throttle at high altitude and would operate at partial throttle at all lower altitudes, or use of an engine to which is added a device to precompress or supercharge cylinder inlet air at high altitudes. Problems in cooling and ignition at high altitude, Diesel-engine operation, steam engines for stratosphere aircraft, and methods of supercharging with special reference to the turbosupercharger are discussed. Design characteristics of stratoplanes are also taken up. Aero Digest, December 1936, pages 32, 34, 77. 1 illus.

The Combustion System of Small High-Speed Compression-Ignition Engines. J. H. Pitchford. The useful speed range of a small compression-ignition engine is certainly no more limited than that of a gasoline engine, providing sufficiently vigorous turbulence can be created to ensure a very thorough distribution of the fuel in the air and a very rapid interchange of heat between the air and the fuel, and providing that no restriction need be placed upon the breathing capacity of the engine in order to realize this degree of turbulence. Combustion chamber design and problems of fuel injection. Engineer, December 4, 1936, pages 592-593. 4 illus.

Dead Center Displacement and Stroke Variation of Radial Engines. F. Wilmanns. Investigation of the upper dead-center displacement of the articulated connecting-rod head. Calculation of the length, lower dead center, stroke variation, diagram of the dead center and stroke variation, and compression chamber and compression ratio. V. D. I., October 31, 1936, pages 1321-1324. 4 illus., 4 tables.

Engineering Research "Spectral Analysis of the Combustion Process." W. Linder. "Motion Process in Gas Columns of Combustion Engines," A. Pischinger. "Heat Transmission by Means of Free Convection on Quadratic Planes," R. Weisse. "Variable Torsional Strength of Grooved Rods," W. Meyer. Abstracts. V.D.I., August 8, 1936, pages 975-979. 12 illus., 1 table.

Looking Ahead to 1937. Engines developing 1000 to 1200 hp. are being installed in new military airplanes as well as in transports. Research and development continues on Diesel engines for aircraft and on larger horsepower in-line, Vee and H-type engines for military utilization. Brief editorial on aircraft production in the United States. Aero Digest, December 1936, page 21.

Some Advantages of the Two-Stroke Cycle Diesel Engine. G. D. Angle. Successful type of two-stroke cycle radial Diesel aircraft engine which has been given flight tests. The ZV 240A was developed by C. Zbrojovka and manufactured in Czechoslovakia. Rated sea-level output is 260 hp. at 1560 r.p.m. and the weight is 653.4 lb. The engine employs a 15:1 compression ratio and, using fuel of 0.882 specific gravity, consumes 0.429 lb. per hp.-hr. Lubricating oil consumption ranges from 0.009 to 0.015 lb. per hp.-hr. Details of construction. Aero Digest, December 1936, pages 22-23. 4 illus.

The Thermodynamic Calculation for Four-Cycle Carburetor Engines. E. Drucker. Exchange of heat and wall temperatures, composition of fuel mixtures and combustion gases, general equation for compression, change of entropy and determination of the constant K of the WÜZ, general equation for combustion, work performed and heat transmission during combustion, equations for expansion, mean working pressure and specific fuel consumption, temperature of the cooling water, exhaust-gas energy, and the discharge of exhaust gases. A. T. Z., October 10, 1936, pages 475-481. 5 illus., 20 equations.

Vibration of Crankshaft-Propeller Systems. K. Luerenbaum. A crankshaft and propeller separated through the interposition of a flexible spring connection is proposed in order to obtain a crankshaft-propeller system which is vibration-free to a large degree within the operating-speed range. Such construction would permit decreased crankshaft dimensions and weight.

Effective measures against vibration are given as: direct elimination of the sources; subsequent destruction or damping of existing vibrations; and changing the pitch of the vibrating system or displacing the resonance points to fields outside of the operating range. This last method is considered the most promising.

Forms and frequencies of the free vibration, questions of vibration sources, resonance points, and stresses imposed on the system by vibration are analyzed and degrees of freedom are discussed with a graphical summary of vibration frequencies. Discrepancies between torque-stand and flight measurements of torsional vibration on the same engine may explain propeller fractures due to the vibration of flexures. Recent fatigue fractures of crankshafts, differing from those due to torsional vibration, must be attributed to longitudinal vibration. In the discussion following W. G. Lundquist analyzes differing radial-engine vibration characteristics. S. A. E. Jour. (Transactions), December 1936, pages 469-478 and (disc.) 478-479. 20 illus., 30 equations. Similar article by same author given as a Report of the D. V. L. Luftfahrtforschung, October 12, 1936, pages 346-356. 21 illus., 1 table.

Engine Testing

Development and Application of the Cathode-Ray Engine Indicator. E. M. Dodds. Applications of the cathode-ray tube to the solution of engine problems such as: indication of pressures in the cylinder and in Diesel fuel lines; mechanical vibration of moving parts; torsional oscillations of shafts; whip of shafts; and time of arrival and duration of flame at any point in cylinder head. The different technique involved when hard-vacuum cathode-ray tubes are used instead of the gas-filled type is also indicated. Observations on the nature of the octane scale are given in so far as its relation to combustion pressure is concerned. A contribution is made to the theory of the mechanism of Diesel knock intensity together with some information on improving the power output and cleanliness of running of a C.F.R.-Pope Diesel engine. It is also shown how different blending agents in a fuel affect the combustion rate after ignition has occurred, and some general conclusions are drawn with regard to detonation in gasoline engines. S. A. E. Jour. (Transactions), December 1936, pages 487-495. 22 illus.

Aircraft Engine Testing. Fiat plant for reproducing high-altitude conditions. Long description including the engine test cell, refrigerating plant, air-pressure reduction plant, artificial wind plant, humidifying apparatus, engine test apparatus, and control board. Automobile Engineer, July 1936, pages 279-285. 15 illus.

Combustion Process in Diesel Engines. K. Karde. Nature and speed of the Diesel combustion process were investigated with the apparatus described and direct ignition-point measurements of fuels were made instead of the determination of cetane and octane number. In view of the ignition delay it was found that indication of pressure by means of the piezoelectric method in the case of usual excess air figures will give more accurate values than the photograph but the end of combustion can be more accurately determined by the photographic method. On the basis of the test results an idea as to the nature of combusion in the Diesel engine is developed which conforms to observation. Comparison of the combustion process in the Diesel and the spark-ignition engine indicated that for maximum speed with good controllability the latter has a favorable characteristic for speed of combustion. A. T. Z., October 25, 1936, pages 501-514. 20 illus., 1 table, 27 equations.

Electric Engine-Testing Plant. Further description of equipment used in a modern electrical aero-engine test laboratory dealing particularly with a combination form of testing machine, partly electric and partly hydraulic, which has some important advantages as regards economy of first cost and convenience of operation. British official requirements and electric brake horsepower indicators are briefly discussed. Heenan electro-hydraulic dynamometers supplied with the Froude wind-tunnel plant to India, Italy, England and Russia are illustrated. Continuation. Aircraft Engineering, December 1936, pages 338-339. 6 illus.

Indicators for High-Speed Combustion Engines. S. Meurer. Free vibration coefficient of the measuring equipment, sensitivity, calibration, installation, shock resistance, and absolute pressure measurement are taken up and the DeJuhasz, Farnborough and DVL glow lamp indicators are compared. Indicators with a constant record of pressure, and the piezoelectric, semi-conductor, inductive, and condenser methods of measuring are described. The possibility of using the cathode-ray oscillograph is discussed. V. D. I., November 28, 1936, pages 1447-1454. 22 illus., 1 table.

Measurement of Fuel Oil Consumption in Internal Combustion Engines. Apparatus described was devised by A. T. J. Kersey and G. W. C. Coy for obtaining continuous measurements of fuel consumption of heavy-oil engines and has been in use at the Royal Technical College. Engineering, July 3, 1936, page 23. 2 illus.

Engines

Aero-Motors at the Paris Show. Vee engines illustrated include: The Lorraine Sterna 12-cylinder water-cooled 850-hp., Hispano Suiza 12 Xirs 12-cylinder water-cooled 690-hp., Russian A.M. 34 F.R.N. 12-cylinder water-cooled 1250-hp., Walter Sagitta I 12-cylinder inverted air-cooled 430-hp. and Sagitta II 470-hp., Renault 12 Ro. V. 12-cylinder inverted air-cooled 450-hp., Farman 12 C.R.S. inverted water-cooled 400-hp., and the Coatalen 12-cylinder water-cooled four-stroke 600-hp. Diesel engines.

The radials include the Bristol Aquila 9-cylinder 507-hp., Bristol unnamed 14-cylinder two-row, Bristol Pegasus 9-cylinder air-cooled 938-hp., Armstrong Siddeley Tiger IX 14-cylinder air-cooled 805-hp., Wright Whirlwind double-row 700-hp., Renault 14 T 14-cylinder air-cooled 1020-hp., Gnôme Rhône M.14 14-cylinder air-cooled 650-hp., and Hispano Suiza 14 A.B.00 14-cylinder two-bank air-cooled 670-hp. engines. The Potez-Lorraine 12D 12-cylinder horizontally-opposed air-cooled 475-hp. engine is also illustrated. Photographs only. Aeroplane Nov. 25, 1936, pages 691-694. 18 illus.

For Light Aeroplanes. Weir 50-hp. four-cylinder, in-line inverted air-cooled engine. A few details. Aeroplane. July 29, 1936, p. 157. 4 illus. Flight, July 16, 1936 p. 91. 2 illus.

French Aviation Show a Display of Technical Development. W. F. Bradley. Greater progress in engines and airplanes has been made during the past two years than during the previous ten years. Air cooling is the outstanding feature and the change to air cooling has not been made to the benefit of the radial but to the in-line type engine. Atmosphere of the show was entirely military. Description of the new engines exhibited with special reference to the Lorraine flat twelve air-cooled 475-hp. engine, designed for reduced frontal area and maximum accessibility, the Gnôme Rhône 18-cylinder 1500-hp. radial, Hispano Suiza engines, and the Coatalen 12-cylinder Vee 550-hp. Diesel engine. Automotive Industries, December 5, 1936, pages 788-791. 8 illus.

G-100. First "heavy-duty commercial engine," designed by engineers of T.W.A. and Wright Aeronautical Corporation, develops 1200 hp. at 2400 r.p.m. at sea level for take-off with 100 octane fuel. Design changes over the G model are discussed and the new Wright soundproofed engine test cells are described with details of the soundproofing. Aviation, December 1936. pages 38-39. 1 illus. United States Air Services, December 1936, pages 32, 37. 1 illus.

Heavy Oil Engines. L. Keuleyan. Conclusions reached by M. E. G. Whitney, Moore and Foster, and Godfrey and Lawrence on heavy-oil engines for aircraft are reviewed and the designs of Renault, Ricardo, Rochefort, British Condor, Salmson, S.S.W., Manufacture D'Armes Polonais, and Junkers are discussed. Continuation. L'Aerophile. October 1936, pages 233-235. 6 illus.

Motors at the Paris Show. Comments on the "L'Aile Volante," Armstrong-Siddeley, "Avra," Bristols, Cirrus-Hermes, Clerget, Coatalen, Farman, Gnome-Rhone, Hispano Suiza, Lilloise, Lorraine-Potez, Regner, Renault, Rolls Royce, Salmson, Train, Russki, Walter, and Wright engine exhibits. A table of specifications of the engines exhibited is included. Aeroplane, Nov. 18, 1936, 664-665, 668. 1 table.

Neat Power. The air-cooled inverted vee-type engine seems to be finding favor abroad. Brief review of engines exhibited at the Paris Aero Show. Flight, November 19, 1936, page 561. 2 illus.

Power at the Salon. An advance has been and is being made with high-powered radial engines and a notable feature of the Show was the evidence that the majority of firms are interesting themselves in a wide variety of types rather than specializing in one particulrar arrangement of cylinders. Horsepower and cylinder arrangement of the engines exhibited are discussed with a table of specifications. Flight, November 26, 1936, pages 575-579. 573, 580. 15 illus., 1 table.

Technical Notes. The Junkers Jumo 205 heavy-oil engine has been supplied with a two-stage turbo-blower operated by exhaust gases. Brief reference. Les Ailes, November 5, 1936, page 5.

Augmented Outputs. Particulars of new models of Bristol engines for the R.A.F. dealing with new gun gear, controllable cooling, and sleeve valves. Specifications for the Mercury VIII and IX, and the Pegasus X, XI, XII, Xc and XX are included. Brief. Flight, July 23, 1936. 1 table.

Continental Engine Practice Examined. Major G. P. Bulman. General trends in engine design, radial versus in-line engines, and critical analysis of the Lorraine flat 12D engine claimed to give 470 hp. for 17 liters and 740 lb. weight, installation of the 860-hp. Lorraine Petrel in the Koolhoven fighter, Hispano-Suiza radials, Gnome-Rhone K-14, liquid-cooled installations, Diesel scarcity, and outputs. Flight, December 10, 1936, pp. 620-23. 7 illus.

Engines. Horsepower, r.p.m., cylinders, and weight only of the following French aircraft engines exhibited at the Paris Aero Show:

Compagnie Lilloise de Moteurs A.6.6: Farman 7 E.D. 190-hp. air-cooled, 9 E.B.R. 265-hp. air-cooled. 12 C.R.S. 400-hp. water-cooled engines; Gnôme Rhône K.7, M.14, K.9, N.14, and L.18 engines; Hispano-Suiza 14.A.B. 670-hp. air-cooled, 12X.I.R.S. 720-hp. air-cooled, 12 Y.d.r.s. 930-hp. water-cooled, and 14 A.A. 1120-hp. air-cooled engines; Lorraine Mizar Major 300-hp. air-cooled radial, Algol Major 420-hp. air-cooled radial, Petrel 720-hp. Vee water-cooled, Sterna 810-hp. Vee water-cooled, Eider 1050-hp. Vee water-cooled engines; Potez 3B 60-hp. radial, 6 Ba 130-hp. double-row radial, 9 Ab 185-hp. radial, and 12.D 475-hp. horizontally-opposed engines; Regnier air-cooled R.2 60-h.p., R.4J. 60-hp., R.4I. 85-hp. R.4 140-hp., R.6 180-hp. inverted, and R.6C. 310-hp. inverted engines; Renault Bengali 220-hp. and Bengali, Jr. 100-hp. engines; Salmson 9A.D.R. 60-hp., 9 N.D. 175-hp., 9 A.B.A. 280-hp., 9A.G.01 350-hp., 6T.E.S. 250-hp. inverted, 12 V.A.R.S. 750-hp. inverted Vee engines; Train 2B.0.1. 20-hp., 4 A.0.1. 40-hp., and 6 C.0.1. 60-hp. engines. Rev. du Ministère de l'Air, November 15, 1936, pages 1428-1441. 6 illus.

Engines. In the advertising section specifications are given in both French and English for the following engines: Coatalen Diesel 12 Vrs liquid-cooled Vee 550-hp. engine; Gnôme Rhône M.14 700-hp., N-14 1100-hp., L.18 1400-hp. radial air-cooled engines; Hispano-Suiza 12X 600-hp., 12Y 800-hp., liquid-cooled, and the 14AB 590-hp. and 14AA 980-hp. radial air-cooled engines; Lorraine Petrel 12HFRS 700-hp., Sterna 12R O.O. 810-hp., and Eider 12Q.O.O. 1200-hp. liquid cooled engines; Renault 220-hp. inverted engine; Salmson 9A.B.a. 230-hp. radial air-cooled, and 12V.A.R.S. 750-hp. air-cooled Vee engines. L'Aeronautique, Supplement November 1936, pages 36-49. 14 illus.

A Flat-Four Engine. Coventry Victor horizontally-opposed 4-cylinder air-cooled engine develops 30 hp. at 3000 r.p.m. for a dry weight of 130 lb. A few details. Flight, July 16, 1936, page 81. 1 illus.

The Four Winds. The weight of the Rolls Royce Merlin 1065-hp. engine is given as 1318½ lb. Brief reference. Flight, December 3, 1936, page 599.

The Harmonic Induction Oil Engine. Ports connecting the lower part of the cylinder to the atmosphere are uncovered at a point which corresponds to a stage of rarefaction, or vacuum, at the inner end of the system formed by the exhaust pipe and the cylinder. Immediately the ports are uncovered a charge of fresh air rushes in and fills the cylinder ready for the next stroke. The frequency of the wave system set up in

the exhaust pipe is a function of the length of the pipe. Description of Petters two-stroke airless-injection engine which has the exhaust valve situated centrally in the cylinder head and the inlet air ports arranged circumferentially around the cylinder. Engineering, December 18, 1936, pages 677-678. 3 illus. Engineer. December 25, 1936, pages 695-696. 4 illus.

Saurer Vehicle Diesel Engine with Exhaust-Gas Turbo Charging. B. Boli. Development undertaken by the Saurer and Arbon companies on high-speed Diesel engines with exhaust-gas turbo charging. A T Z, October 25. 1936, pages 519-522. 6 illus.

Sterling Crankless Engine. New oil-burning two-stroke power plant is to be built primarily for marine use but is adaptable for other purposes. Automotive Industries, December 19, 1936, pages 856-857. 2 illus.

Still Higher Efficiency. Some of the improved Bristol engines and new components described in the July 23 issue. Photographs only. Flight, August 6, 1936, page 160a. 6 illus.

Technical Notes. Results of test of excess power and excess pressure obtained on the Lorraine Petrel 12 Hfrs engine which developed 1120 hp. on the ground, 1015 hp. at 800 m., and 1060 hp. at 600 m. Reference is also made to the fact that satisfactory results were obtained with the Sterna 810-hp. engine in 50-hour and 40-hour tests. Brief. Les Ailes, November 19, 1936, page 10.

Accessories

Controllable Cowls. In the controllable cowling of the Bristol Aeroplane Company the flaps are moved from 0 to 30 degrees by screws turned through sprocket wheels and an endless chain which runs inside the back support-ring of the cowling. A few details. Aeroplane, July 29, 1936. 2 illus.

Hydraulic Remote Control Units. Control system used by Imperial Airways and the Royal Air Force for engine control, control of trim tabs, flaps, and retractable landing lights. Few details. Aero Digest, November 1936, page 61.

Preheating Apparatus for Airplane Engines. Benzine-heated apparatus, developed by Luft Hansa for use in starting aircraft engines in cold weather, produces 150,000 calories per hour. By means of the apparatus the three engines of an airplane of the Junkers Ju 53 type may be warmed up in from 15 to 20 minutes with an efficiency of 30 to 35 per cent. V D I, October 24, 1936, pages 1301-1302. 2 illus.

Wright 3-Way Drive. In order to apply the Hamilton Standard constant-speed governor to the Whirlwind engine, Wright Aeronautical Corporation designed the new accessory drive described which can be used on all 7- and 9-cylinder Whirlwinds regularly equipped with the two-position hydro-control mechanisms. Aviation, December, 1936, pages 35-38. 2 illus. Aero Digest, December, 1936, page 54. 1 illus.

Cartridge-Type Engine Starter. Coffman engine starter developed by Federal Laboratories has already given satisfactory performance in field cold-weather tests conducted by the U. S. Army Air Corps, Naval Air Service, and the Marine Corps. Few details. Aero Digest, November, 1936, page 60. 2 illus.

Keeping Out the Dust. A range of air filters by Vokes and their application to radial and in-line engines. Brief. Flight, August 27, 1936, page 236. 5 illus.

The Starting of Diesel Engines. E. Hiller. The various methods described include hand, electric, compressed-air, and flywheel starters. Cartridge and electric hot-spot means of facilitating ignition, means of increasing the compression ratio, air preheating the cooling water are discussed. V D I, October 31, 1936. pages 1309-1316. 13 illus.

Meteorology

Destructive Easterly Gales in the Columbia River Gorge, December, 1935. D. C. Cameron and A. B. Carpenter. Pilots using this airway estimated wind velocities at 4000 ft. to be about 30 m.p.h. when the surface velocities averaged about 50 m.p.h. As pilots were not flying in the air stream, the estimate was based on the very rapid rate at which clouds from the upper portion of the inland lake of cold air just below the inversion were flying westward over a 4000-ft. ridge. Weather conditions at Crown Point, Oreg., during this period, erratic behavior of the Airway beacons, and observations of pilots are referred to. Monthly Weather Rev., August, 1936, pages 364-367. 2 illus.

Modern Methods of Weather Forecasting. Lt. Colonel A. Verdurand. Discussion of the meteorological phenomena which distinguish the masses of polar air from those of tropical air includes: the determination by radio soundings of the origin of the examined masses of air which produce the fronts; way in which a radio sounding permits the determination of the origin of a mass of air; origin of gusts and thunderstorms in masses of air in unstable equilibrium; origin of zones of haze and mist in mass of air in stable equilibrium; primary importance of differences of temperature in the generation of meteorological phenomena; equipment, methods, and expense of radio soundings.

The second part of the article is devoted to the organization of the system of sounding adopted by the French National Meteorological Office. services rendered to aerial navigation, and utilization of the observations collected by the Office. Photographs of apparatus. Rev. de l'Armeé de l'Air, October, 1936, pages 1105-1127. 9 illus.

Aircraft Radio

General Purpose Airport Receiver. R C A Model AVR-11 receiver, designed especially for airport and airline ground-station service, covers all the frequencies in present use for aviation service, the standard entertainment band, and the high-frequency bands up to 23,000 kcs. Few details. Aero Digest, November, 1936, page 60.

Instrument Landing for Aircraft. H. W. Roberts. Pan American Airways, Lorenz, Zeppelin-Telefunken, Loth electromagnetic, and Simon systems of instrument landing are described. Concluded Aero Digest, November, 1936, pages 32-34, 36. 10 illus.

New Anti-Static Antennas for High-Speed Aircraft. H. W. Roberts. "Rain static" interference with aircraft radio investigated by T.W.A. and United Air Lines. Results obtained are discussed. The 10-in. anti-static loop antenna developed by T.W.A. for both audio reception and radio direction finding, and the United 18-in. antenna are described. Aero Digest, December, 1936, pages 36, 75. 2 illus.

A New Visual Radio Direction Finder. F. W. Dane. A circle of light immediately appears on the indicator of the Dane direction finder if either the transmitter or receiver unit fails in operation. The direction finder is a visual-indicating system which can be used not only as a homing device but also for cross bearings. Design and operation described. Aero Digest, November, 1936, pages 48-49. 3 illus.

R C A Crystal Unit. The Model AVA-8 Crystal Attachment provides crystal control of any two frequencies in the aviation communications band of 2000-6500 kc. Crystals are of the "V"-cut low-temperature coefficient type mounted in R.C.A. Model AVA-10 crystal holders. Few details. Aviation, December, 1936, page 39. 1 illus.

The Leader Cable Method. E. Fromy. Leader cable method of guiding airplanes in landing. Results recently obtained in tests made on the basis of more accurate information on the cable field formation. Reference is made to fundamentals of the cable field presented in the original article and dealing with an elliptical field in which the direction of rotation reverses above the vertical leader cable, and to formulas given for the calculation of the magnitude of the field at every point and of its elliptical form. The abstract reviews the results of tests made at Chartres and Bourget. From Rev. Gén. Elect. 39 (1936). E T Z, November 19, 1936, pages 1353-1354. 3 illus.

Radio Approach Systems at Croydon. To provide a practical test of radio intended to assist aircraft approaching airports under conditions of bad visibility, the Lorenz, Plessy and Marconi systems of radio beacons have been installed by the British Air Ministry at Croydon airport. A few details of the installation. Brief. Engineering, December 25, 1936, page 703.

Training Radio Operators. W. E. Crook. Method of producing radio personnel for British civil airlines with illustrations of the facilities provided by Air Service Training, Ltd. at Hamble. Aircraft Engineering, December, 1936. pages 340-342. 8 illus.

Air Forces

Europe Beats Us in the Air. There are between 25,000 and 30,000 war planes in the various defense forces of Europe. Germany alone probably has 7000 military airplanes now and is producing them at the rate of at least 10,000 a year. Russia recently announced that she has the largest air force in the world. Although Italy probably does not have as large an air force, there is little doubt that the quality is first rank. France has fallen behind and England is in a frenzy trying to catch up with Continental powers. Camouflaging of new military planes has become general practice. Some pursuit planes carry as many as eight guns and a 23-mm. cannon mounted in the motor. Comments of S. P. Johnston, editor of Aviation, on European production of military airplanes. Business Week, December 12, 1936, pages 46-47. 3 illus.

The Armies of Europe. L. Hart. "In one way, however, the Russian Army is better equipped than any other to bring about the breakdown of the enemy." Reference is made to the new Russian parachute forces in a general comparison of the armies of Great Britain, France, Germany, Italy and U.S.S.R. Foreign Affairs, January, 1937, pages 235-253.

Those Cherished Secrets. The strongest Air Force in Europe is said to be that of Italy which has a wonderful organization of aerodynamic laboratories and an airplane with a range of 2000 miles, a top speed of 273 m.p.h. and a bomb capacity of 1½ tons. France has a bomber with a range of 2480 miles, top speed of 242 m.p.h. and a ton of bombs. Germany has a machine with a range of 1200 miles, top speed of 304 m.p.h. and ¾ ton of bombs. England is said to have only two types of bomber, neither a heavy bomber, the first having a range of 1000 miles, a speed of 140 m.p.h. and a load capacity of 1¼ tons of bombs, and the second having a range of 960 miles, top speed of 145 m.p.h. and a load capacity of ¾ tons of bombs. Reference to debate in the House of Lords. Aeroplane, December 2, 1936, page 704.

AUSTRALIA

News in Brief. The British Air Ministry will begin filling Australia's order for 90 aircraft for the R.A.A.F. Eighteen Seagull V amphibians, 36 Hawker Demon fighters, and 36 Avro Anson twin-engined reconnaissance bombers have been ordered. A total of 2000 officers and men fully trained is planned. Brief reference. Aero Digest, November, 1936, page 80.

BRAZIL

Foreign Activities. Special features of the Stearman 76-C3 military trainers thirty of which have been ordered for the Brazilian Air Corps. Brief description. Aero Digest, December, 1936, page 70. 1 illus.

CANADA

Foreign News in Brief. The Royal Canadian Air Force is now receiving new equipment recently purchased in Britain at a cost of more than $500,000. Seven Shark bombers being delivered have a maximum speed of 175 m.p.h. and a 7-hour duration. Brief reference. Aero Digest, December, 1936, page 71.

The Four Winds. Five Vickers Supermarine Stranraer flying boats with Pegasus engines are being built for the Royal Canadian Air Force at a cost of £156,000. Brief reference. Flight, December 10, 1936, page 624.

FRANCE

Organization of the Air Ministry and Staff of the Armée de l'Air. The French President's decree of September 14, 1936, on the organization of the Air Ministry and Air Force Staff. Rev. du Ministére de l'Air, November 15, 1936. pages 1480-1488.

GREAT BRITAIN

The House of Lords and National Security. Further debate on the defense of Great Britain. Aeroplane, December 2, 1936, pages 707-710.

Air and Water. The Air Ministry has placed an order for a number of Miles Hawk trainers and Nighthawk trainers. Brief reference. Engineer, December 4, 1936, page 603.

The Defense Debate on the Address from the Throne. Debate on the British Government's defense policy. Aeroplane, November 18, 1936, pages 635-636.

The Fleet Air Arm. Possibility that the control of the Fleet Air Arm will be changed from the Royal Air Force to the Navy is considered and advocated in an editorial. Flight, November 19, 1936, pages 537-538.

The Health of the R.A.F. in 1935. Incidence of sickness shows a decrease of 6 per 1000 of strength below that of 1934 for cases admitted to hospitals and sick quarters and is the lowest figure recorded. A total of 51 deaths in the earthquake at Quetta was the main cause of the increase in the incidence of deaths for the total Force. Of the 96 deaths from injury 17 were caused by flying accidents, 12 by motorcycle accidents, and one by a wound while flying on Active Service. An investigation by station medical officers of the Air Defense of Great Britain on the psychological effects of fatigue in flying is mentioned with references to other research. Aeroplane, November 25, 1936, page 680.

The House of Lords and National Security. Debate calling for full information on the measure of rearmament already achieved and the program for the immediate future. The Air Minister's answer deals with the problem of officers, pilots and airmen, training methods, acceleration of new types of airplanes and engines, the shadow industry, confused policies, balloon barrage, and a ministry of supplies. To be continued. Aeroplane, November 25, 1936, pages 675-679.

More Haste, Worse Speed. "The bulk of the airplanes being made, just at the moment, are of types which were designd at least seven years ago and probably a bit more. We doubt whether most current machines which are classed as bombers could cover much more than 300 miles in one trip . . . . The great Shadow-Aero-Motor Industry is to be turned round to produce in quantities a type of motor, admittedly the most powerful for its weight today, which is in fact already obsolete because a newer and quite different and provedly superior type is just about going into production." The suggestion is made that the Air Ministry try out the first-half dozen of the new bombers as mail machines in charge of civil pilots before bothering about arming squadrons with them. Brief discussion of Mr. Churchill's cry for more speed in armament production. Aeroplane, November 18, 1936, page 634.

No. 48 (General Reconnaissance) Squadron. Major F. A. De V. Robertson. Activities of this General Reconnaissance Squadron and a few details of the Avro 652 Anson. Flight, December 3, 1936, pages 604a-604d. 5 illus.

On International Impertinences. C. G. Grey. A typical Grey discussion reviewing international questions and the Spanish civil war, with references to recent incidents in Japan, Persia, and Africa and their effect on British prestige. Aeroplane, December 9, 1936, pages 734-736.

Overseas Strength. Squadrons are to be formed in Hong Kong, Ceylon, East Africa, and Panang and the Fleet Air Arm is to be increased by 50 per cent. Brief reference. Aeroplane, December 9, 1936, page 737.

ITALY

Aerial Control of Ethiopia. Pilot D. Vecchi. Opportunity for cooperation of air and ground forces in the military and political control of Ethiopia. Aspects and needs of the air force and prospects for the use of groups of parachutists are analyzed. Report of the activities of the military director is discussed. Rivista Aeronautica, October, 1936, pages 1-9.

SOUTH AFRICA

Convertible Performance. Of the seven Airspeed Envoys for South Africa four are primarily for use with South African Airways, but are capable of rapid conversion into military aiplanes in three hours. Three are for the South African Air Force as fast medium bombers. Both versions can carry an unspecified load of bombs in racks under the wing, an Armstrong revolving gun turret above the fuselage, and a single fixed gun in a trough immediately behind and beside the pilot who has the normal bead and ring sights in front of his screen. With 305-hp. Cheetah IX engines the maximum speed of the civil version is 210 m.p.h. Flight, July 2, 1936, pages 13-15. 3 illus.

TURKEY

The Four Winds. A special Monospar S.T.25 has been ordered by the Turkish State Air League for parachute jumping. Brief reference. Flight, November 26, 1936, page 573.

U S A

Aviation Activities of the United States Navy. Rear Admiral A. B. Cook. Important accomplishments during the 1936 fiscal year with brief references in regard to instrument flying, training of Naval aviation cadets, lighter-than-air activities, reserve training, static direction finding, photography, recommendations on the Naval airship situation, funds made available, construction work assigned to the Naval Aircraft Factory, maintenance tour of inspection, development of engines and aircraft, and number of new engines and aircraft delivered. Aero Digest, December, 1936, pages 16-20, 75. 13 illus.

Rearmament in the Air. Once the United States was first in quantity and quality but now is fifth or sixth in quantity, and claims of leadership in quality are seriously threatened. Brief editorial urging sufficient appropriations by Congress for new planes and equipment. Aero Digest, December, 1936, page 21.

U S S R

The Four Winds. A Russian A.N.T.-6 monoplane fitted with four AM-34 800-hp. engines has reached 29,460 ft. carrying a 5-ton load.

It is claimed that aircraft flying on Russian arctic routes have carried 5,400 passengers and 900 tons of freight a year, flying 12,900 hours and covering 1,666,600 miles.

There are about 600 parachute jumping towers in the U.S.S.R. and last year 800,000 jumps were made from them. Brief references. Flight, November 26, 1936, page 573.

The Four Winds. Two Fairey Feroce biplanes, latest Belgian-built version of the Fantome, have been ordered by U.S.S.R. Hispano "moteurs canons" are specified giving a speed of 270 m.p.h. Brief reference. Flight. December 10, 1936, page 624.

Air Warfare

Aerial Defense. M. Dekeyser. Air defense of an air force while it is on the ground. The author suggests the increase in the number of Civil air bases equipped for wartime uses, equipment of other territory left alone for agriculture, increase of mobility of the air force, experiments in the use of catapults, regrouping of the units destined for defense of the industrial zones, and practical tests of the resistance of sheet-iron hangars subjected to effective bombardment. From Revue Hebdomadaire, No. 39, 1936. Rivista Aeronautica, October, 1936, pages 51-53.

Capital Ships and Air Attack. The British Admiralty do not claim that a ship can be invulnerable in all circumstances but they think that the capital ship of the future can be so designed as to distribution of her armor on decks and sides and as to interior subdivision that she will not be subject to fatal damage from the air. Points from the Report on the Vulnerability of Capital Ships to Air Attack published by a subcommittee of the Committee of Imperial Defense, including reference to experiments made by the Admiralty and Air Ministry. Aeroplane, December 9, 1936, page 736.

Every Dog Has His Day. Captain N. MacMillan. Big multi-engined fighters and line-ahead fighting tactics with broadside by shell-firing guns are predicted. The author would like to see the development of higher muzzle velocities for aircraft machine guns, the general adoption of light explosive shells for aircraft armament (for that is said to be the best way to damage modern metal aircraft structure), and large multi-engined aircraft with everything sacrificed to speed except the power of hitting. Discussion of future fighter tactics, aircraft, and armament. Flight, July 16, 1936, pages 79-81. 1 illus.

Offensive and Defensive Airplanes. Possibilities of the modern bomber and the deficiencies of the single-seater pursuit airplane. The discussion includes the multi-engined multi-place bomber as an excellent offensive arm, bombardment, comparison with the single-engined single-seater, and defensive aviation of today for which fleets of single-seaters only are being built. Rivista Aeronautica, October, 1936, pages 10-18.

FRANCE

Foreign News in Brief. In the nationalization of all aircraft manufacturing concerns supplying the French government, four companies have been formed for the construction of airplanes and seaplanes with a capital provided two-thirds by the State and one-third by private interests. Each company takes over aeronautical manufacturing firms in one of the four districts into which France has been divided. Brief reference. Aero Digest, December, 1936, page 73.

How France Has Nationalized Her Aircraft Industry. R. C. Wood. Plans and administrative methods are explained. Flight, November 19, 1936, page 551.

U S A

A Few of the Things It Is Hoped Congress Will Do—Quickly. "There is a fairly general feeling in the industry that the present system of procurement, based on the Aircraft Act of 1926, is working well and there is a hope it will be allowed a further trial . . . . the trouble has largely been due to different interpretations of the law by the Army, Navy, and the Comptroller General . . . . Funds should be made available, either directly or indirectly, to enable a nucleus of manufacturers to push research and development, not only of aircraft itself, but of methods of producing them in an emergency." Editorial. U. S. Air Services, December, 1936, pages 8-9.